Principles and Practice of

Lasers in Otorhinolaryngology and Head and Neck Surgery

edited by
V. Oswal
M. Remacle

co-editors
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C. Hopper

Second Edition

Volume 1

PRINCIPLES AND PRACTICE OF LASERS IN OTORHINOLARYNGOLOGY
AND
HEAD AND NECK SURGERY – 2ND EDITION

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PRINCIPLES AND PRACTICE OF LASERS IN OTORHINOLARYNGOLOGY AND HEAD AND NECK SURGERY

Second enlarged edition

edited by V. Oswal and M. Remacle

co-editors S. Jovanovic, J. Krespi, S. Zeitels and C. Hopper

Kugler Publications/Amsterdam/The Netherlands

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Foreword

In this era's informational paradigm, while pondering the considerations to be penned in this foreword, the relevance of a text such as this emerged progressively as the focal point. After all, for years, one established source for accessing large amounts of valuable information had been the Encyclopaedia Britannica, a printed tome, which is no longer relevant. Instant access to the latest scientific information is freely available to all with an internet. So, what can this text provide that cannot be readily accessed?

In contemplating given topics, the Editors, as most certainly occurred in this publication, chose clinical authorities to author chapters in their areas of expertise. The experienced clinician often finds such a forum a unique opportunity to reflect on years of knowledge acquisition and then render an insightful discourse on the lineage of his/her current understanding of the topic. On the other side of the coin, the reader instantly acquires a knowledge base, which was validated with an exhaustive literature search and gains the senior authors' perspective of it. A less experienced author will benefit from thoroughly reviewing the currently available science and technology and moreover, gain experience in scientific writing. In the latter scenario the senior author is at once mentor and expert.

Under ordinary circumstances, from the concept outline submission to a publisher, the time line to completion of the text is approximately one and a half to two years. Recruiting and assigning authors, awaiting late manuscript submissions and editing are unquestionably time consuming. Yet a passionate, dedicated Editor will take seemingly varied submissions and script them into a worthy finished product. Such was the case with this publication. The end result is a superbly structured text covering most of the concepts relating to the topic in a format that is both logical and intuitive.

At the risk of some redundancy, I share with you my thoughts on some of the significant number of new additions and improvements made to this second edition. The chapter on risk management is a welcome contribution. The rationale for the shift in the current decision tree for laryngeal cancer as it relates to macro versus micro margins, improvements in voice quality and the choice of initial therapeutic considerations are appropriately vetted. The rethinking of HPV associated malignancies is a new and most important addition. Zeitels' presentation of angiolytic lasers for benign and malignant pathology is state of the art. I particularly enjoyed reading about lasers and the association with tropical diseases. The chapters on robotic surgery, non-invasive cartilage reshaping and photo-diagnostics puts the latest technical innovation in our discipline into perspective. The excellent illustrations and photographs are a bonus. There are other areas that could be mentioned e.g. paediatrics, however, the aforementioned has more than adequately established the tenor of the text.

In their quest to provide a one-stop knowledge base of a reference quality, it is inescapable that the size of the final proof would surpass the typical numbers of between four and five hundred pages for the hard bound volume. Tightening the text by removing some peripheral material would deprive the book its very objective of a reference quality publication. The obvious solution was to present the work in a set of two volumes, and the editors and the publishers have to be congratulated in achieving this seamlessly. The natural anatomical split provides the reader with a convenience of picking up the volume of relevance for the task at hand.

An unusual feature is the inclusion of MCQs after each chapter, to serve as a test for recall of knowledge, the result of which can be assessed simply by going back to the chapter!

The Editors and the publishers have exploited the now ubiquitous electronic media network to their advantage. Operating on various platforms a dedicated website will complement the book with updates, operative videos, and means of communication to share the knowledge globally.

It was the focus of this brief foreword to explore the relevance of this text in the current informational climate. It provides the essential foundation for informed thought on this topic. Agree or disagree with the information contained within, the reader has acquired the knowledge to be able to do such.

With this text you will be rewarded for sitting in your most comfortable chair, thumbing through the pages and sensing the new print. Immediately understood will be the time and effort it took to complete a text of this calibre. Read the chapters first that initially appeal to you and then without question you will read the remainder. This book should be in the library of any serious student of the subject.

I feel privileged to have been asked to write the foreword.

Marshall Strome

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Preface

First edition (2002)

The last two decades of the twentieth century saw the introduction of a number of lasers in clinical practice. A need to rationalise their use was obvious and to cater for the need, the book entitled *Principle and Practice of Lasers in Otolaryngology H & N Surgery* was published in 2002. Its aim was to present in a structured and systematic way the basic laser science, the effects of various wavelengths on the living tissue (tissue interaction) and its role as an *additional* device for surgical procedures. An accompanying CD contained comprehensive video demonstrations of a range of laser operative procedures.

The contributions came from near and far afield, providing a wealth of personal experience. Most chapters also contained literature review on the topic, thus ensuring a diverse viewpoint. The risk and benefit issue was addressed in each chapter so that the laser was not branded as a magic bullet for all ills. An extensive bibliography at the end of each chapter gave references for further, in-depth reading.

The editors took a deliberate decision to provide sufficient details of the disease or dysfunction in which the laser usage was advocated. This approach in no way intended to do away with the more traditional books, but to provide a ‘one-stop’ knowledge base which would put the laser usage in perspective for that condition.

It is gratifying to note that the publication acquired a status of a reference book and was a sell-out within a decade, not a small feat for a highly-specialised subject matter. A reviewer observed:

‘This is an excellent comprehensive, good readable reference book for the otorhinolaryngologist who has an interest in laser surgery or has already own clinical practices. It should be ready on hand in each ENT-clinic where lasers are used. [...] I would strongly recommend this publication for otorhinolaryngologists who want to acquire a complete up-to-date reference book dealing with any aspect of lasers in ORL.[1]’

Second edition (2014)

A need for a further print run prompted us to undertake extensive research to ascertain if a second edition rather than a print run was warranted. A consensus was reached to write a second edition which will bring the book up to date and remain so in the foreseeable future.

From the conceptual beginning of writing the second edition, this work has taken three years to come to fruition. There are 67 chapters with an additional material in the appendix, from 59 international contributors who have been selected for their expertise in a particular laser topic.

The layout of the second edition

Similar to the first edition, the formatting of the chapters has been uniformly maintained throughout, for ease of reading. Each chapter is sumptuously presented with high-quality colour photographs.

In this second edition, we have rearranged the contents. While sectional arrangements follow the well-trodden path of the anatomical regions, the chapters within the section are rearranged so that a disease or a dysfunction entity is the leader. The emphasis has thus shifted to everyday clinical conditions seen in a busy practice of an average clinician. As an example, laryngeal pathology is now divided in to *non-obstructing* and *obstructing* lesions. The latter requires a dedicated set up, since skill and equipment requirements are both high and demanding. Acute airway obstruction due to malignancy can be managed with the laser, thus avoiding tracheostomy. However, there is a potential to fatality and therefore, a separate chapter describing the management in great details.

There is increased incidence of non-tobacco-non-alcohol (NT-NA) cancer of the oral cavity in the Western hemisphere, particularly in the younger age group (Cohen *et al*. 2009). Increased oro-genital contact appears to be the principal risk factor for HPV-associated oral cancers in NT-NA group (Gillison, 2008).

Early detection of subtypes involved in RRP will allow a targeted vaccination programme to prevent full expression in later life. In order to make otolaryngologists aware of this changing demographics, Recurrent Respiratory Papillomatosis (RRP) now appears under a broad heading of Human Papilloma Virus Infections.

There is an increasing acceptance of the laser excision as a preferred mode of management in *early* glottic cancer. Here again, the emphasis has shifted from removal of the lesion with a macroscopically clear margin to a frozen section *microscopic* clearance, in an attempt to minimise the removal of 'normal' tissue for a better voice outcome.

Office-based laryngeal surgery is making inroads, thanks to a better quality imaging and also due to escalating inpatient costs. Hand in hand, angiolytic lasers are being used to selectively ablate the blood supply to a pathological lesion which is then allowed to involute naturally. Steve Zeitels has undertaken much pioneering work in this regard and his philosophy is aired in a chapter under 'Office-Based Management of Laryngeal Pathology'.

Laser is also being used as a non-surgical modality to correct deviated cartilaginous nasal septum and protruding ears. For a research-oriented readership, we have allocated a chapter on the basic science of cartilage reshaping, detailing the intricate mechanism involved in this new fascinating *non-surgical* application. Refinement of this technique may lead to harvesting cartilage and reshaping to fill a gap following excision of a segment of trachea involved in extensive stenosis.

There is an increasingly vocal body of professionals who advocate an acceptance of Photodynamic Therapy (PDT) as the forth modality in the management of cancer, along with time-honoured conventional management strategy with surgery, radiotherapy and chemotherapy. Again, we have allocated separate chapters for basic PDT science and its clinical applications.

Early diagnosis of a cancerous lesion or its recurrence following an apparent cure is a cornerstone for the successful outcome of this potentially fatal condition. Contrary to a common belief, the so-called optical biopsy is not used to interrogate normal from an abnormal tissue; rather, it is used to identify areas of differentiation in tissues with similar clinical characteristics, *e.g.*, dysplasia versus carcinoma *in situ*, hyperkeratosis, inflammation and neoplasia (Swinson *et al*. 2006). We hope the chapter on optical biopsy will stimulate further research in this cost-effective, user-friendly and low-skill method to monitor cancer cases on outpatient basis.

Laser usage in chronic ear disease has a limited application. However, John Hamilton has produced some impressive figures on successful application of KTP laser in reducing the incidence of recurrence of cholesteatoma and more such reports are necessary to confirm this important laser application.

Socio-economic conditions of many populous countries have thus far prevented the routine use of laser technology in clinical practice. Of late, emerging markets with their financial strength are changing the demographics, and laser is being used more frequently to address some clinical entities peculiar to tropical regions. A chapter on 'Lasers in chronic tropical inflammatory diseases in otolaryngology' provides some newer applications for the laser technology.

In the section dealing with future trends, there appears a chapter on the role of biofilms in maintaining chronicity of certain conditions such as rhinosinusitis and chronic tonsillitis. Laser is used to disrupt these colonies of microbes and help patients recalcitrant to the conventional surgical and antibiotic management.

A chapter on photochemical internalisation is truly a tomorrow's world concept. Berg *et al*. (2005) examined the possibility of photochemically damaging the endocytic vesicles and thus releasing macromolecules into the cytosol, opening up the possibility of tissue-specific targeting for cancer therapy, gene therapy and vaccination at a *sub-cellular* level.

It is inevitable that robotic surgery would enter our speciality at some stage, and fibre-delivered lasers are ideal to cohabit!

The main body is followed by Appendices. Appendix I provides a useful list of topics covering 'core of knowledge' of laser technology Understanding the scientific basis of any technology optimises its use and laser technology is no exception. Appendix II contains a template for formulating local rules for optical radiation. Appendix III covers a useful glossary of terminology associated with laser and light related technology, for a quick reference. Appendix IV describes the use of Low-Level Laser Therapy (LLLT) in

the management of chronic cochlear tinnitus. We have included this topic under 'Appendix,' since there is no consensus as to its effectiveness in the management of tinnitus of unknown aetiology. As to any risk associated with this unproven therapy, there is one report from Nakashima in 2002 of a patient experiencing acute hearing loss after the third laser treatment. Prospective readers are advised to read the literature in detail before embarking on this, yet inconclusive application of the laser technology.

In their passion to provide the readership with the most up to date and yet in-depth knowledge base, there was an inexorable addition of pages after pages by the authorships. Before long, the usual number of 400 to 500 pages for a hardback cover had surpassed. When the constant barrage of text was exhausted, both the Editors and the Publishers were faced with a daunting task of incorporating all the material in one large volume containing in excess of 900 pages. Inevitably, a decision was taken to present the work in a set of two volumes and we hope the physical separation has been achieved unobtrusively.

The readership

The basic laser science is given a generous six chapter lead. We believe that the grasp of the basic science is essential for *every* member of the team in order to optimise the surgical outcome. *E.g.*, maintaining the equipment at peak performance level by the laser technician is as important as the surgeon using the correct parameters.

A dialogue with the nursing staff to apprise them of the proposed procedure goes a long way towards smooth running of the list – this point has been reinforced in a chapter on paediatric laser surgery and also in the laser management of acute airway obstruction. In the latter situation, the authors of the chapter rightly point out that a lack of the usual team – *e.g.*, due to staff holidays etc. – is a *contra-indication* to laser surgery for acute airway obstruction due to malignancy and we are in complete agreement with this philosophy.

Ignition of the tracheal tube is much more likely at the hands of laryngologists, and detail description of various aspects of this totally avoidable mishap had been so amply covered in the first edition that, over a decade later, there is no new material in the chapter on 'Anaesthesia for laser airway surgery'. We believe that it is an essential reading for our anaesthetic colleagues engaged in anaesthesia for laryngeal laser surgery.

On the other hand, surgical fires involving drapes, skin preps, beards and body hairs are more of a reality while operating in the head-and-neck area. A new chapter has been added in the basic science section which covers these and other hazards in greater detail.

It is worth noting that surgical fires are not only caused by the laser, but also other energy-based devices such as diathermy and cautery.

As before, we have included an expanded version of glossary in the appendix and also, a sample record keeping which should be adopted as per your own institutional policies on lasers.

In a multi-readership publication such as this book, our aim is to keep each chapter, a stand-alone chapter. It is therefore inevitable that there are some repetitions, but as before, these are kept to a bare minimum.

MCQ

Another new feature in the second edition is the multiple choice question (MCQ) tests for the contents of each chapter, along with correct answers. In some cases, it is likely that there may be a conflict of answers in the overall context of the subject matter. However, the MCQs relate to the material of each chapter only, and the answers have been approved by the authorship(s) of the chapters.

Website link

In the 2002 edition, we had included a CD-ROM containing 44 short video clips, some over five minutes in length, and slide shows, demonstrating various laser surgery procedures. In conjunction with the text in the hard copy, this interactive medium provided a virtual operating theatre experience and was much appreciated.

In this second edition, we deliberated if we should follow the same format of interactive multimedia experience for the readership. One of the drawbacks of this excellent resource is that once produced, it remains frozen in time.

We then considered a dedicated website in conjunction with the hard copy rather than a DVD. A website has a number of advantages. It provides unlimited data handling. It can be updated so that its contents always remain contemporary. It can provide a forum for discussion. It can also provide a thread for expressing opinions on a particular topic. Please refer to www.kuglerpublications.com/lasersorl for more information on this project.

Acknowledgements

The editors

The second edition would not have been possible without the support and the enthusiasm of my editor colleague Marc Remacle.

Joe Krespi and Sergije Jovanovic are joined by Steve Zeitels and Colin Hopper as co-editors. Marc and I extend our gratitude for their work to make this publication possible. Each section is overseen by section editor(s) and again, we appreciate their advice on the contents of their respective sections.

The contributors

There is no doubt that institutional and professional demands on the practicing clinicians have increased considerably in the past decade all over the world. Health-care costs have escalated, and therefore, value for money and quest for increasing productivity. Migration from operating theatre to the office-based facility for certain laryngeal procedures is a prime example of cost constraints. We do absolve any such methods which would cut the cost of health care and bring it within the reach of a greater proportion of the population. Alongside, we do not see any measures which will improve the quality of the care as pejorative.

Armed with the resource from the internet websites, patients have become more knowledgeable and their expectations have increased. Various statutory bodies have put an onus on the clinicians to keep themselves abreast of advances in medicine and have introduced periodic revalidation. It is hardly surprising that an extra activity of contributing a chapter to a book can be tiring and gets put on the back burner. We acknowledge the extra burden we have put on our contributing authors by pestering them to keep within the time schedule. Their Herculean effort deserves applause for sharing their knowledge and experience with us, and more importantly, for the young professionals who would benefit from the wealth of their experience.

Simon Bakker of Kugler Publications and his team also deserve special thanks for bringing this second edition to publication for the benefit of our profession.

As before, my wife Nirmal has provided an unwavering input which led to the conclusion of this work.

Envoi

Our words would be incomplete without recalling some of the milestones which brought us where we are today with the laser technology.

We have come a long way from when, in 1919, Einstein presented *Zur Quantumtheorie der Strahlung* (*The Quantum Theory of Radiation*), followed by various advances in understanding the phenomena which ultimately led to Maiman building the first ruby laser in 1960 (Maiman, 1960) with a wavelength of 690 nm.

The application of infrared emission lasers using pure carbon dioxide, nitrogen, and helium, that operated continuously at 10,600 nm, was reported by Patel *et al.* (1965). Jako in 1967 applied the laser in laryngeal microsurgery on a cadaver larynx (Jako, 1972). Clinical application commenced in 1972, when Strong and Jako presented their first report on use of the CO_2 laser on 12 patients (Strong and Jako, 1972). Some ten years on (1981), the Senior Editor carried out several bench experiments and determined parameters for its routine use in laryngeal surgery. Hand-on training courses were also established using animal tissue model in simulated environment. This pioneering work in clinical practice led to the publication of the book titled 'CO2 laser in Otolaryngology and Head and Neck Surgery' a quarter of a century ago, in 1988.

Vasant Oswal, MB, MS, FRCS, DLO, DORL
Senior Editor

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Introduction to multiple-choice questions

V. Oswal

1. Introduction

Standard multiple-choice items consist of two basic parts:

1. A problem (a question as stem);
2. A list of suggested solutions (answers as alternatives).

The stem may be in the form of either a question or an incomplete statement. The solutions consist of a list of alternatives with one (or more than one) correct or *best* answer, and a number of incorrect or *inferior* answers or distractors.

2. Varieties of multiple-choice responses

These range from one single correct response to more than one, or a combination of two or more responses or, sometimes, a negative response. Answers which have homogenous responses require a *best answer* as the correct response. The most commonly used response is the one with a single correct response.

3. Uses of MCQ

Multiple-choice test items as self-learning activity are adaptable to various level, from simple recall of knowledge to more complex levels, such as the reader's ability to comprehend concepts and principles, apply them to new situations, interpret cause-and-effect relationships, discriminate between fact and opinion, and so on. In the context of laser technology,

- a test item related to the effect of changing a parameter (rule using) will have 'increased or decreased collateral damage' as the correct answer;
- a test item related to the correct application of principle will have 'KTP laser as a preferred laser while dealing with a vascular tumour (problem solving)', as the correct answer.

4. Objectives of including MCQs in this book

Laser technology has a high skill demand, and as such it is generally used by established surgeons or their trainees at advance level. The book is aimed primarily at this readership that requires a practical knowledge base for using the laser correctly and safely in their individual practice.

The MCQs have been included in this work as a simple tool for recall of knowledge, the result of which can be assessed simply by going back to the chapter!

While the general structure of the MCQs follows the well-trodden path, the correct answer is not limited to just one option. Rather, many questions have more than one correct answer. We believe that this variant will have a greater impact on the revision of the salient points which will be useful in their clinical practice rather than score a required percentage of correct answers to pass an examination. By taking the MCQ test, it is hoped that the prospective readers will get a useful insight of the lasers as applied in everyday practice. They can then modify the use of laser to suit their individual preferences and practices. MCQs may provoke a correspondence pertaining to the validity of some of the questions and, in particular, the choice of correct answers provided at the end of the book. The editors welcome such interaction from the readers and suitable discussions will be published online. Please send correspondence to the Senior editor: Vasant Oswal, VOswal@aol.com.

About the editors

Vasant Oswal

Mr Vasant Oswal is an Emeritus Consultant Otolaryngologist – Head and Neck Surgeon at the National Health Service (NHS) hospital in Middlesborough in the County of Cleveland in England. The hospital is named 'James Cook University Hospital' after the explorer and navigator Captain James Cook (1728-1779) whose birth place is in Marton, a suburb of Middlesborough. Vasant Oswal's interest in the laser technology dates back to the seventies of the last century. Recognising its potential as an *additional* instrumentation in Otolaryngology, he acquired the Coherent® CO_2 laser in 1981 – one of the very first ones in the UK – by *public donation*! Much pioneering work was undertaken, mostly by bench experiments, to establish parameters for appropriate surgical procedures. Dedicated instruments were designed and plume evacuation systems were introduced. Based on Norton *et al*. (1978),[1] a 'metal' tube was fabricated by stripping the outer rubber casing of Kuhn's tube (1902),[2] to demonstrate the fire-proof property of its inner metal component. This work culminated in the design and commercial production of 'Fireproof Oswal-Hunton flexo-metallic anaesthetic tracheal tube'. The First British Conference on CO_2 Lasers in Otolaryngology was held in Middlesborough under his chairmanship in 1983. The first Hands-on International Cleveland Laser Course was run in conjunction with the conference and still continues as an annual event, some thirty years later. His pioneering work led to the publication of the books *CO_2 laser in Otolaryngology and Head and Neck surgery* in 1988[3] and *Principles and Practice of Lasers in Otolaryngology-Head and Neck surgery* in 2002.[4] The latter work acquired the status of a reference book and went out of print, hence this updated second edition containing some 30% additional material covering the advances of the last decade.

Vasant Oswal established a number of laser training courses internationally. He has also been awarded an honorary membership of otolaryngology associations of many countries. He has written and presented widely on various laser topics. He has chaired laser sessions at the international conferences organised in countries all over the globe. He is an Associate Editor of Lasers in Medical Science and member of the editorial board of a number of laser journals.

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- Founder member and Honorary Vice President, British Medical Laser Association, UK
- Founder member and Honorary Secretary General, European Laser Association
- Founder and Chair, Education committee, British Medical Laser Association, UK
- Founder and Faculty member of the International Cleveland Laser Course, England
- Founder and Chair, Laryngology and Voice Association, India
- Founder and Chair, Journal of Laryngology and Voice, India
- Chair, Postgraduate Jury selection board. The International Academy of Otolaryngologist and Head and Neck Surgeon, Russia
- 'Actual Member by invitation': 'Distinguished Otolaryngologist', The International Academy of Otolaryngologist and Head and Neck Surgeon, Russia
- Honorary Treasurer, World Federation of Laser Societies, Japan
- Honorary member of International Academy of Laser Medical Science, Florence, Italy
- Fellow of the American Society of Laser Medicine and Surgery, USA

- Fellow of the Royal Society of Medicine, England, UK
- Gold Medal: ‘NP Simanovskii Gold Medal’ awarded by the International Academy of Otolaryngologist and Head and Neck Surgeon, Russia
- Past Faculty member of Eustachian tube laser surgery course, Geneva, Switzerland
- Past Faculty member of International Voice Care and Laser Voice Surgery Course in Paris, France
- Past Visiting Faculty member of the International laser course, Mont Godinne University Belgium
- Past Faculty member of laser surgery course, Egypt
- Past external examiner, University of Malay, Malaysia
- Past honorary Editor-in-Chief, ENT News, UK

Facilities and Orations named in the honour of Vasant Oswal

- ‘Oswal Rhinology Suite’, James Cook University Hospital, Middlesbrough, Cleveland, UK
- ‘Vasant Oswal Voice Disorder Clinic’, Deenanath Mangeshkar Hospital, Pune, India
- ‘Vasant Oswal Oration’, British Medical Laser Association, UK
- ‘Vasant and Nirmal Oswal Oration’, International Cleveland Laser Course, UK
- ‘Vasant Oswal Oration’, Laryngology and Voice Association, India

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Dr. Remacle chairs the joint commission of the Free University of Brussels and the Catholic University of Louvain for the master's degree in Logopedics. His interest in laser surgery led him to contribute to the development of dedicated devices, such as the micromanipulator and microinstruments. He initiated the new scanner and the new robotic micromanipulator for laser-assisted incision and dissection. He contributed to the development of the CO_2 laser wave-guide. Along with his colleague Prof. Georges Lawson, he initiated the TransOral Robotic Surgery (TORS) in Belgium.

He presented numerous communications and published papers principally on laser-assisted microsurgery and microphonosurgery. He regularly takes part in International courses and conferences on laser microsurgery. He is on the scientific board of the following journals: *Annales françaises d'ORL et de chirurgie cervico-faciale (Paris)*, *Acta Oto-Rhino-Laryngologica Belgica*, *European archives of Oto-rhino-laryngology*, *Annals of Otology, Rhinology & Laryngology*.

Dr. Remacle is currently:

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- International member of the American Broncho-Esophagological Association
- Corresponding member of the American Head & Neck Society
- Corresponding member of the American academy of ORL- Head & neck Surgery
- Corresponding member of the French society of ORL and Head & Neck pathology
- Member of the French society of Head & Neck Carcinology
- Member of the French society of Phoniatrics
- Member of the Belgian society of ORL and Head & Neck Surgery
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Prof. Sergije Jovanovic is an academic adjunct professor of ENT, Head and Neck Surgery, currently working in a private practice. From 1995 until 2010, he held a position as Vice Chairman, and head of specialized training in ENT and Plastic Surgery at the ENT Department of the Benjamin Franklin Medical Center, Charité, Universitätsmedizin, Berlin, Germany.

Since 1989 he has carried out much research and pioneering work in order to establish criteria for CO_2 laser stapes surgery and other otological laser applications. In 1997 he published his thesis on 'The application of new laser systems in stapes surgery', for which he was awarded the Anton von Tröltsch Prize by the German Society of ENT Medicine, Head and Neck Surgery. In 1990 he performed the first laser stapedotomy with a CO_2 laser. Between 1994 and 1999 he contributed to the development of dedicated devices and different types of scanner systems for otological laser applications. This enabled him to establish a suitable selection of laser parameters to undertake a single-shot footplate perforation of preselected diameter ('one-shot' technique). In 1999, for the first time worldwide, the surgical technique of 'one-shot stapedotomy' was introduced by him, representing a considerable advance in CO_2 laser stapedotomy.

He has published many papers and presented lectures at many national and international conferences and has been a faculty member at numerous national and international surgical courses. He has acted as director and organizer of many national and international laser courses on otolaryngology, head and neck surgery held in Berlin. His interest on the field of the management of congenital vascular lesions (hemangiomas and vascular malformations) of head and neck lead him, along with other well-known national and international specialists, to establish the 'Center for Vascular Malformations (ZVM)' in the St. Joseph Hospital, Berlin. The center provides a comprehensive treatment of congenital vascular lesions and promotes the collaboration of scientific and clinical research in this field.

Prof. Jovanovic is currently a member of:

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- German Society for Laser Medicine
- German Society for Plastic and Reconstructive Surgery
- Professional Association of the German Society for Plastic and Reconstructive Surgery
- European Rhinology Society
- European Academy of Facial Plastic Surgery ('The Joseph Society')
- Politzer Society
- International Society for Laser Surgery and Medicine

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Dr. Krespi is Associate Director at the Head & Neck Surgery Service Line, North Shore-LIJ Health System, Director of the Center for Sleep Disorders, New York Head & Neck Institute and Professor of Clinical Otolaryngology at Columbia University.

Dr. Krespi, an internationally recognised otolaryngologist, is an expert in in-office laser surgery, endoscopic sinus surgery and surgery to relieve snoring/sleep apnea. He is one of New York's pioneer surgeons in laser uvulopalatoplasty, a cure for snoring. He is an authority on management of oral malodor, also known as halitosis, and management of chronic rhino-sinusitis. Highly involved in the professional community, he has gained recognition from his medical colleagues through various honours, including the American Academy of Otolaryngology Head and Neck Surgery Honor Award and American Medical Association Physician's Recognition Award.

He has held other honourable titles, including President of the NY Head and Neck Society and President of The NY Laryngological Society. With over 200 published works in the field and numerous awards, Dr. Krespi is a go-to expert for national media such as references in Wikipedia and CBS News where he was a featured expert in a series relating to laser treatment for eliminating bad breath. Dr. Krespi has been mentioned as a top otolaryngologist in *New York Times Magazine* 'Super Doctors' and has been listed in the annual list of 'Best Doctors' in *New York Magazine.*

Steven Marc Zeitels

Dr. Steven Marc Zeitels is the Eugene B. Casey Professor of Laryngeal Surgery at Harvard Medical School and the Director of the Massachusetts General Hospital (MGH) Center for Laryngeal Surgery. He is an internationally recognised specialist in managing complex throat, voice, and larynx problems. In 2004, the first endowed Chair in Laryngeal Surgery at Harvard Medical School was created for him while he re-established a Harvard Laryngeal Surgery service at the MGH, which had not been present since the 1920s.

Dr. Zeitels has received more than 75 awards and honoured lectureships for his achievements including the Casselberry and Newcomb Awards from the American Laryngological Association, the Broyles Maloney Award of the American Broncho-Esophagological Association, and the Distinguished Alumnus Award from the Boston University School of Medicine. In 2012 he was ranked 14 in Fast Company's '100 Most Creative People'. The British Medical Laser Association awarded him the 'Vasant Oswal Oration 2012' which he delivered in London, England, during the laser conference convened by European Laser Association.

He has authored more than 200 scientific articles, book chapters, and videos as well as presenting over 400 papers and lectures. *Zeitels' Atlas of Phonomicrosurgery* is a leading textbook in microsurgery of the larynx. He serves or has served on the editorial board of five national and international journals. Dr. Zeitels is a prolific surgical innovator having designed numerous new procedures and instruments, while holding a number of patents for these innovations. He is widely acknowledged for pioneering novel laser applications to treat papillomatosis, dysplasia, and cancer as well as creating conventional office-based laryngeal laser surgery. Most notable was his introduction of angiolytic laser treatment of vocal cord cancer, which conjoined Judah Folkman's concepts of tumour angiogenesis and Rox Anderson's theory of selective photothermolysis.

Dr. Zeitels' work has been discussed extensively in print media, radio, and television including NY, LA, and London Times, Wall Street Journal, Rolling Stone Magazine, National Geographic Channel, BBC, and all major networks in the USA.

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Mr Colin Hopper is an academic Oral and Maxillofacial Surgeon/Head and Neck Surgeon at University College London and University College London NHS Hospitals Foundation Trust in England. He has conducted preclinical and clinical research into optical diagnosis and photodynamic therapy in relation to head and neck cancer and pre-cancer and has worked closely with the National Medical Laser Centre at UCL.

He has published extensively on both optical diagnostics and photodynamic therapy with over 400 published abstracts and peer reviewed articles and has lectured in over 40 countries. He has extensive clinical experience with PDT in a number of applications for benign and malignant disease of the head and neck.

His current positions include:

- Founder member and immediate past president Head and Neck Diagnostic Society
- President Elect European Platform for Photodynamic Medicine
- Executive member, British Medical Laser Association
- Executive member, International Photodynamic Association
- Founder Member, International Academy Oral Oncology
- Member, British Association of Oral and Maxillofacial Surgeons
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Section I: Basic Laser Science

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Chapter 1

History of laser light

J. Abitbol and R. Sataloff

Creation of light and fire has intrigued mankind throughout history. Pythagorus, the Greek philosopher, proposed the first theory of visible light in the sixth century BC, in which he stated that an object is made visible because light waves travelled outward from the eyes. Yet visible light is only a small part of the light spectrum. In 1704, Newton published his corpuscular theory, which held that light consisted of rapidly moving particles. Huygens, an opponent, maintained that light was a series of waves. The English physicist, J.C. Maxwell, developed the first electromagnetic theory of light. Light waves, he stated, were electrical in nature and different from the mechanical nature of sound waves. Many phenomena of light, such as propagation, reflection, refraction, interference, diffraction, and polarisation were explained by the electromagnetic wave theory. But the absorption and emission of light by matter remained unexplained until Hertz proposed the photoelectric emission theory in 1887, in which he stated that a photoelectric emission is independent of the intensity of light, but dependent on the wavelength of the incident light. This incident light induces the ejection of electrons from conductors of light. These effects were defined by Einstein in 1905 as the absorption of light energy by matter. According to Max Planck's theory published in 1900: "Light is corpuscular in nature but apparently travels in electromagnetic waves emitting radiant energy by tiny packages of energy called quanta." Einstein extended the Planck theory, and stated that light energy transferred by matter must be transferred in discrete units, or 'quanta'. Einstein later postulated that the energy of a light photon was proportional to the frequency of the light.

The equation between 'quanta' and 'wavelength' was defined: $e = h\ \eta$
(e = quantum energy, h = Planck's constant, η = wavelength)

If the electromagnetic theory is believed to be true, electrons must emit energy as they revolve around the nucleus, or spirally towards the centre of the atom, and collapse into the nucleus. The same theory states that all atoms emit a continuous spectrum of energy because the frequency of radiation emitted by the revolving electrons must be equal to the frequency of revolution. This was in contradiction to the line spectra theory that had been previously described. Proposing the first postulate of the atomic theory, Bohr held that: electrons can revolve around the nucleus of an atom in certain stable orbits without emitting radiant energy. The second postulate held that an electron makes a transition from a stable orbit to a lower energy level orbit by emitting a photon. The photon emitted has an energy equal to the difference between the two orbits, and the photon is the emission of radiant energy. Bohr's model

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explains only the emission spectra of an atom; it does not predict what energy level elements and molecules should have, or the emissions they should give off. To explain this, an understanding of quantum mechanics is required.

The theory of quantum mechanics states that energy levels can be predicted and explains the frequency of light observed in the atomic spectrum. In 1919, Einstein presented *Zur Quantumtheorie der Strahlung* (The Quantum Theory of Radiation). In his theory, electrons, atoms, molecules, and photons interact with electromagnetic radiation of quantum units by three types of radiation transitions: absorption, spontaneous emission, and stimulated emission. Absorption of a photon occurs when an electron goes from a lower orbit to a higher orbit. The electron is in an excited state, which is unstable. Light, thermal, electrical, or optical energy can induce this kind of excited state.

Spontaneous emission of a photon occurs when the electron goes down to its stable orbit. Stimulated emission was the genius idea of Albert Einstein. He discovered that one photon of a specific wavelength could interact with an excited atom to induce the emission of a second photon. Laser-produced light operates on that principle: in a stimulated emission, the second photon emitted from the excited atom has the same frequency, the same phase, and the same direction as the incident photon absorbed and immediately released. Chapter 2 covers the various aspects of laser light and its effect on biological tissue.

A laser produces a beam, like a sunbeam, but with four fundamental characteristics: intensity (tremendous energy in a very focused, narrow beam), coherence (in phase spatially and temporally), high collimation (light waves are parallel with minimal divergence and thus minimal dissipation of energy), and monochromacity (uniform wavelength). This last characteristic is fundamental from a surgical point of view because specific tissues such as muscle or bone absorb a specific wavelength. The components of human tissue absorb wavelengths selectively, based on their state of hydration, temperature, colour, and thickness.

Radiation emitted from a laser consists of a spectrum of wavelengths ranging from 200 (ultraviolet) to 10,000 (infrared) nanometres (nm). The surgical lasers in current use emit approximately 500 nm (argon laser), 1060 nm (neodymium: yttrium-aluminium-garnet laser or Nd:YAG), 532 nm (KTP), 640 nm (dye laser), diode laser, and 10,600 nm (the CO_2 laser, most commonly used in laryngeal surgery).

The idea of using light energy for surgery predates the laser. In 1945, Gerd Meyer Schwickerath treated detached retinas and eye tumours with sunlight. The first proposed use of lasers in surgery occurred in 1958 by Schawlow (published by Maiman and Townedes). Maiman built the first ruby laser in 1960 (Maiman, 1960) with a wavelength of 690 nm. The application of infrared emission lasers using pure carbon dioxide, nitrogen, and helium, that operated continuously at 10,600 nm, was reported by Patel *et al.* (1965).

Preliminary laboratory studies using a 20-watt CO_2 laser for liver surgery in dogs were reported by Yahr and Strully (1966). Their results were encouraging and led to application of the laser in laryngeal microsurgery by Jako in 1967 on a cadaver larynx (Jako, 1972). Clinical application commenced in 1972 when Strong and Jako presented their first report on use of the CO_2 laser on 12 patients (Strong and Jako, 1972).

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Chapter 2

Laser biophysics

H. Moseley and V. Oswal

1. Introduction

Albert Einstein first postulated the principle, governing the *emission by stimulation*, as far back as 1917. But it was not until 1954 that the first *stimulated emission* was achieved in the *microwave* region of the electromagnetic spectrum and described aptly as MASER (Microwave Amplification by Stimulated Emission of Radiation). In 1960, Theodore Maiman produced a red laser light in the visible spectrum by stimulating a ruby crystal and thus the first laser (Light Amplification by Stimulated Emission of Radiation) was born. Within the short time span of 12 months, the ruby laser light was being used in ophthalmology for photocoagulation. The ruby laser was also the first experimental laser to be used in otolaryngology in 1965, on the inner ear of pigeons. As further wavelengths became available, the experiments in otolaryngology were extended to the otosclerotic footplate (Nd:YAG, 1967) and otic capsule (argon, 1972). However, it was the CO_2 laser that received general acceptance in otolaryngology, since its properties eminently suited the requirements of soft tissue ablation, particularly in the treatment of laryngeal pathology. Today, as we enter the second decade of the 21st century, the surgical laser has come a long way from its origins as a theoretical possibility postulated in the principle of stimulated emission in 1917. The CO_2 laser has been in routine use as a workhorse laser in otolaryngology all over the world since the 1980s.

2. Ordinary light versus laser light

Radiation from a conventional light source is emitted over a wide range of wavelengths, or spectrum. The beam leaves the source randomly, in all possible directions. When the emission takes place in the visible part of the spectrum, we call it light. The light intensity close to the source is very high. As the observer moves away, the intensity tails off rapidly. The loss of intensity is due to the divergent nature of the conventional radiation. The divergence can be reversed and intensity restored by placing a magnifying lens in its path. By adjusting the distance between the lens and a piece of paper placed underneath, the sun's rays can be brought into sharp focus on the paper. The intensity at the focal point can increase sufficiently to burn paper, as we all can recall from our childhood experience. Another example of focusing the light to increase its intensity at a distance is seen in the construction of a search-light.

In contrast, the laser produces a beam with a very *narrow divergence* (Fig. 1). Light leaves the source with a high degree of collimation and a very small divergence. As the beam travels in space, the directionality is maintained over a long distance. As a result, high beam intensity is also maintained over a long distance. Thus the power per unit area is much higher, so much so that the laser beam can be used to weld metal.

Conventional light can be hazardous to the eye

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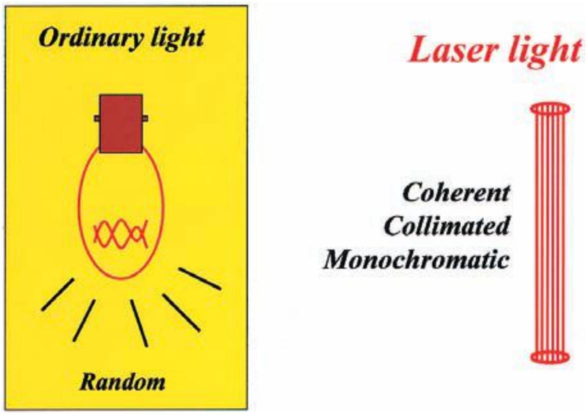


Fig. 1. Ordinary versus laser light.

and the skin, particularly at close range and in focused mode. It is common knowledge that unprotected skin will blister if exposed to strong sun rays. A skier protects his eyes from ultraviolet (UV) rays by wearing sun goggles. Laser radiation of sufficient intensity and exposure time can also cause irreversible damage to the skin and eye. The most common mechanism of laser tissue damage is its thermal effect, ranging from causing proteins to denature at moderate intensity to vaporisation at high intensity. The thermal damage process occurs in the band-spread from near UV at 315 nm to far infrared at 10,000 nm, including visible radiation (400-780 nm), and at an exposure time of greater than 10 msec. The damage following pulsed exposure also seems to be thermal, if the pulse duration is greater than 10 msec.

Apart from thermal damage, the laser can also cause *photochemical* damage following exposures to either ultraviolet radiation (UVC: 100-280 nm, UVB: 280-315 nm and UVA: 315-400 nm), or shortwave visible radiation (400-550 nm).

3. Lasers for otolaryngology

The surgical management of pathology in the respiratory and food passages has some distinctive features. Access to these areas is difficult and restricted. The passages are dark cavities lined by *vascular* mucosa, and intraoperative bleeding obscures the view of the surgical site. Significant postoperative oedema may ensue, and jeopardise the airway.

Due to their unique properties, lasers have cer tain advantages over conventional methods. Their surgical application can be enhanced by in-depth appraisal of these properties (laser physics) and how they react with biological tissues (tissue interactions). The delivery of the laser energy (laser delivery systems) to the surgical site in dark and narrow passages poses a challenge. Finally, unlike conventional surgical tools, lasers are a powerful source of energy with the potential for accidents and hazards to patients and theatre personnel alike. Their safe use (*laser safety*) is at least as important as their clinical application (Chapter 3). This is particularly so in laser surgery of the larynx, where the presence of a flammable anaesthetic tube presents a constant potential source of explosive fire, with very unpleasant consequences. In the following pages, we will cover these various aspects, not in any random way, but in an integrated package for the otolaryngologist, whose learning objectives are always going to be *rational* and *hazard-free* laser usage in everyday surgical situations.

4. Removal of tissue by the laser beam

As the CO_2 laser beam strikes the tissue, the temperature rises and the intra- and extracellular water boils. The cell expands due to steam formation, and explodes. The contents are released as steam and smoke. The subsequent and progressive application of the laser beam results in further loss of tissue, layer by layer, thus increasing the *depth* of tissue removal. When the intended depth is achieved and the beam exposure is stopped, there remains a layer of coagulation, which is not viable. The *eventual* amount of tissue loss is therefore a combination of the vaporised as well as the coagulated tissue. Apart from the irradiance of the beam, the interaction between the tissue and the laser energy (tissue interaction) also contributes significantly to the tissue removal, as will be discussed later.

For the successful removal of tissue, the energy must be delivered to the tissue in a sufficient concentration to raise the water temperature to 100°C. If the beam is moved rapidly on the surface of the tissue, the energy may not be sufficiently high to vaporise the tissue. The movement of the beam is completely under the control of the operator, and determines the depth of surgery.

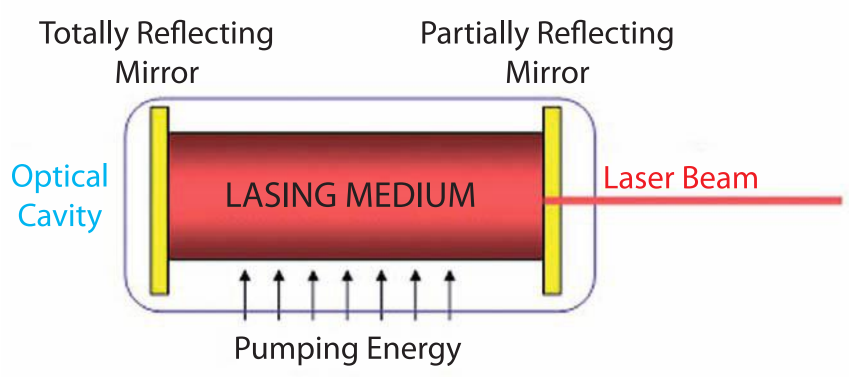


Fig. 2. Components of a laser.

5. Laser light

5.1. Mechanism of production of laser light

A laser consists of the lasing medium, contained in an optical cavity, and a pumping system, provided by external energy. The mirrors at each end ensure that the photons bounce back parallel to the axis, so that they, in turn, collide with excited atoms and stimulate further production of photons. The components of a laser are shown in diagrammatic form in Figure 2.

The term ‘laser’ is not a device notation, but rather describes the *process* of production and *amplification* of light. The device where the laser action takes place is called an optical cavity, a tube containing a suitable lasing medium which may be gas (*e.g.*, CO_2), liquid (*e.g.*, dyes), or crystal (*e.g.*, ruby). The medium may be doped with other substances or passed through a second crystal to change the wavelength and resultant tissue effects. Thus, the Nd:YAG laser, emitting at 1064 nm, is frequency doubled by passing the light through potassium titanyl phosphate to produce the KTP laser, which then emits at 532 nm. As a result, the tissue effects of the KTP laser are altogether different from those of the Nd:YAG laser.

Atomic processes are responsible for the production of laser light. An atom consists of a dense nucleus, around which electrons move in orbit. In the normal stable state, the electrons occupy a lower *ground state*. The orbiting electrons are free to change their orbit to a different (higher) level. They do this by absorbing energy from an external source, which may be light (photons), electrical discharge, or by some other means. The electrons go into a higher orbit and the atoms are said to acquire an *excited*, unstable state.

All matter in the natural state is at the lowest possible energy level. Therefore, the unstable electrons cannot stay in the higher unstable orbit. They tend to decay to a lower, more stable orbit. In the process, they lose the extra energy of the higher level in the form of packets of energy, or *photons*. The amount of energy lost by the electron is equal to the difference between the excited and decayed states of the electron. This may happen *spontaneously* and at random. The randomly occurring *spontaneous* emission of radiation is disorderly or diffuse, and if it occurs in the visible spectrum of the electromagnetic spectrum, it produces normal incoherent ‘light’. Spontaneous emission can also occur in the infrared or ultraviolet part of the spectrum, which is invisible.

Albert Einstein postulated that a photon released from an excited atom might interact with another similarly excited atom. This results in the second atom releasing its photon, which is *identical* in every respect to the first photon. This phenomenon is called *stimulated* emission of radiation. In this stimulated emission, the number of photons has doubled, from one to two. The two photons have the same direction of travel, and are in phase. In turn, the two photons stimulate two further excited atoms and cause them to lose their photons. We now have four photons with exactly the same properties as the original ones. Several repetitions of stimulated emissions produce orderly photons, much like a battalion of soldiers marching in unison on a parade ground.

Since further energy is continuously being pumped in, many more atoms acquire an excited state – a state of *population inversion*, in which more atoms are in the excited state than in the stable ground state.

The laser tube contains two mirrors, one of which is fully reflective whereas the other, at the other end, has a small aperture and is thus only partially reflective. As photons strike these mirrors, they are reflected back into the lasing medium where they stimulate other atoms to emit more photons. The process repeats itself several times with an enormous surge in the number of photons. A small fraction of energy is allowed to escape through the aperture of the mirror, and this is the *laser beam*.

5.2. Properties of laser light

The term 'light', as used in everyday life, only covers that part of the electromagnetic radiation spectrum that is visible to the human eye. However, a number of surgical lasers emit radiation in the invisible infrared and ultraviolet part of the spectrum. In strict sense, therefore, laser light is not light but rather radiation. Nevertheless, laser radiation does obey the normal laws of optics, although with some unique properties. It is *monochromatic*, *collimated* and *coherent*.

Monochromatic laser light has the very narrow bandwidth of a single wavelength. Different lasers emit at different wavelengths. All tissues absorb radiation to a certain degree – but the *absorption* reaches its peak when the wavelength of the radiation matches the *absorption coefficient* of that particular tissue. This is *selective* absorption. Maximum selective absorption at the point of strike results in very little conduction of energy away from the point of strike, thus minimising the collateral damage. Therefore, it makes sense to use the laser with emission at the wavelength maximally absorbed by the tissue type to be treated. In otolaryngology, the air and food passages are lined with water-rich mucosa. CO_2 laser emission is highly absorbed by water. It is hardly surprising, therefore, that the CO_2 laser has become the mainstay of laser management in otolaryngology.

Collimated laser light is directional, whereas ordinary light is *diffused*, scattering randomly from its source. A good analogy for ordinary light is that of passengers alighting from a crowded train and then dispersing randomly. In contrast, the laser light has virtually no divergence. It is often described as a 'pencil of light'. Unlike ordinary light, the collimated laser beam can be transmitted to the surgical site by a series of reflections from mirrors placed on the inside of the tube of an articulated delivery arm, and will still remain collimated. Alternatively, it can easily be focused on the end of an optical fibre of less than 400 µm in diameter, and transmitted to sites with in the body. The beam emerging from the tip of the optical fibre is no longer collimated, and starts to diverge at an angle of between 14 and 20°.

With coherent light, all waves are in phase both in time and space. The property of coherence is exploited directly in non-linear photo-acoustic breakdown effects for laser destruction of urethral stones. The coherence is short-lived and is lost within a few mm of the passage of the beam in tissue. During use, the CO_2 laser is focused on a small spot of about 0.1 mm. This produces a very intense irradiation and vaporises the tissue. Thus, it is necessary to adjust the target depth accurately as the tissue removal progresses, so that the subsequent layers of tissue remain within the focal parameter of the beam. Beyond the focal point, the beam diverges, the spot size increases progressively, hand in hand with distance from the source.

6. Laser energy

With conventional surgery, energy contained in a sharp scalpel is constant. Any increase in the rate of tissue removal can only be achieved by increasing the pressure and motion of the blade on the tissue. On the other hand, the energy contained in the beam is controlled by adjusting its parameters on the machine. There are three such parameters: power, energy, and duration of exposure.

The *power* of the beam is the rate at which energy is delivered. It is expressed in watts. Power in watts = energy in Joules / time in seconds.

The *energy* is expressed in Joules and is a measure of amount of work performed by the beam. Energy in Joules = power in watts x time in seconds. Continuous wave (CW) lasers such as the CO_2 are expressed in watts, whereas pulsed lasers such as the holmium:YAG (Ho:YAG) are expressed in Joules per pulse.

The *duration* of the application of the beam is expressed in seconds or fractions thereof.

6.1. Irradiance

The laser beam is a highly concentrated amount of power in a small area. The power per unit area is termed *irradiance* or *power density*. It is measured as watts (W) per square cm, and is calculated by dividing the power of the beam by its crosssectional area. Thus, a beam may have a power of 10 W and an area of 1 cm^2, giving an irradiance of 10 W per cm^2. On the other hand, the same 10W power over 1 mm^2 will have a very high irradiance or power density (1000 W/cm^2). Laser power expressed in watts without any reference to the irradiance or power density has no particular relevance. For example, for the removal of a particular tissue, an advisory 10-W setting is only half the story; to complete it, the spot size must also be included so that the irradiance can be calculated.

A collimated beam will retain its irradiance over a long distance from the laser aperture due to very low divergence. On the other hand, a beam leaving the tip of an optical fibre will diverge immediately, and its irradiance will be determined by the distance between the tip of the fibre and the target tissue. The irradiance determines the effect of the laser beam on a particular tissue. A high irradiance will vaporise the tissue, whereas low irradiance will simply coagulate it.

6.2. Beam diameter

For a given amount of radiated energy, reduction of the spot size increases the concentration of that power over the entire area of the spot. The power density is thus inversely proportional to the square of the spot diameter. At any power setting, a small spot size has much higher irradiance than a large spot size. In clinical practice, very high ablation density can be obtained at a relatively low power setting by reducing the spot size. For example, a precise and sharp incision line can be created on the vocal cord by using a small spot size of 250 μm, in order to carry out phonosurgery at relatively low power settings.

6.3. Modes of operation

The beam output from the machine can be in various modes, which are time-based. In the CW mode, the beam output is stable while its power can be varied. The CO_2 laser operates in the same way as a CW laser. The single pulse laser has a pulse duration of a few hundred microseconds to a few milliseconds. Q switching is an electronic shutter that allows a high build-up of energy within the tube. This is then released over a very short duration of a few nanoseconds, reaching an enormous peak power. Scanning devices operate at a fixed (or variable) pulse rate of from a few pulses per second to as many as 20,000 pulses per second.

7. Different types of lasers

Lasers are named according to the lasing material they contain. Four types of material are used: solid, gas, liquid, and semiconductors (or diodes). The Nd:YAG laser is a solid state laser containing an yttrium-aluminium-garnet crystal, which acts as a host for neodymium ions. Gas lasers use a single gas or, more commonly, a mixture of gases. The best known example of this type is the helium neon (HeNe) laser, which contains a mixture of helium and neon gas as the lasing medium, and emits at 632 nm in the visible red spectrum. It is most commonly used as a pointer and also, superimposed onto the path of invisible infrared lasers, as an aiming beam. Nowadays, diode lasers have virtually replaced the HeNe laser. Other gas lasers are the CO_2, emitting at 10.6 μm, and the argon and krypton gas lasers, emitting at multiple wavelengths. Dye lasers use organic dyes as the lasing medium and are characterised by their 'tunability'. A broad range of emissions at or near the visible spectrum is possible, depending on the dye used and its concentration. Semiconductor diode lasers have two layers of semiconducting material sandwiched together. Although they emit at low power, they are built as arrays in order to provide sufficient power for clinical use. Despite this construction, they are physically very small, portable, and cheap. The best example is the gallium-arsenide-diode laser, with a central emission at 800-840 nm. The most commonly used lasers are described below in some detail, and are listed in Table 1. It may be useful to consider different lasers according to their application.

A. *Surgical Lasers* These include the CO_2, Nd: YAG, Ho:YAG, Er: YAG Diode
B. *Photodiagnostic Lasers* These are almost exclusively diode lasers (Chapter 66)
C. *Photodynamic Therapy* Traditionally this was carried out using a tunable dye laser, but now it is either performed using a diode laser (for systemic cancer) or LED (superficial skin cancer) (chapters 41-43)

Table 1. Characteristics of lasers commonly used in medicine

Laser type	Wavelength	Power/energy	Duration	Beam delivery
Argon	488, 515 nm	3-10 W	0.1-10 sec	fibre optic
CO_2	10.6 µm	10-60 W	0.1-10 sec	articulated arm/waveguide
CO_2 (superpulse)	10.6 µm	250 W peak	200 µsec	articulated arm/waveguide
Dye (flash lamp-pumped)	577, 585 nm	15 J	400 µsec	fibre optic
Excimer (argon fluoride)	193 nm	0.1 J	20 nsec	direct
Gallium arsenide (diode)	850 nm	50 mW-60 W	continuous or pulsed	fibre optic
HeNe	633 nm	1 mW	continuous	fibre optic
Ho:YAG	2.1 µm	2 J	300 µsec	fibre optic
KTP	532 nm	15 W	quasi-continuous	fibre optic
Nd:YAG	1064 nm	100 W	continuous	fibre optic
Q-switched Nd:YAG	1064 nm	20 mJ	10 nsec	fibre optic
Ruby	694 nm	3 J	1 µsec, 25 nsec	fibre optic
Erbium YAG	2.94 µm	0.05-1.0 J	100-300 msec	fibre optic

The argon laser

The argon laser was one of the first to be used for clinical applications. It principally emits at 488 and 514 nm in the visible blue/green spectrum. The beam is easily transmitted down a fibre and can be focused to a very small spot size of only 100 µm. It has been used successfully for treating diabetic retinopathy and other retinal vascular conditions. Its high absorption by haemoglobin has been exploited in treating vascular skin lesions such as port wine stains and haemangiomas, but the relatively long pulse duration renders these lasers sub-optimal for this application.The newer air-cooled models are much smaller and do not require connection to a water supply, which may be difficult to maintain. Moreover, they do not require such high-current electrical supplies as the early models.

The carbon dioxide laser

The CO_2 laser has also been in use for some time. It emits at 10.6 µm, in the far invisible infrared region. A visible red HeNe or diode laser is accurately superimposed onto the path of the CO_2 beam and acts as an aiming beam. The CO_2 remains the 'workhorse' laser in most medical fields, including otolaryngology, because of its excellent cutting properties with very little lateral tissue damage. It does not have any specific electrical requirements and operates from a standard electrical supply. Its micromanipulator attachment allows coaxial delivery of the energy for laser surgery with the operating microscope, thus considerably extending its range of clinical applications. Refinements in technology with the sealed laser tube have removed the need for external gas cylinders.

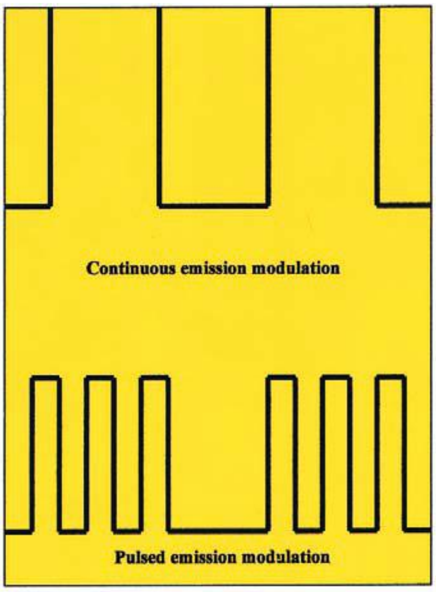


Fig. 3. Continuous and superpulse mode. In the superpulse mode, laser energy is delivered with each peak over an extremely short period of a few nanoseconds. The peaks are interspersed with *rest* periods when no exposure occurs, allowing time for tissues to cool down. (Courtesy M. Remacle)

Another technical innovation contained in the CO_2 laser is the so-called *'superpulse'* (Fig. 3). The CO_2 laser is modified to deliver peaks of energy higher than its own average power. With superpulse, the laser delivers the energy in a train of pulses rather than in a continuous beam. The frequency of pulses with superpulse is less than 1000 pulses per second. With ultrapulse, the CO_2 beam is excited by radiofrequency and thus produces a very high frequency mode. The temperature of the tissues rises during the peak, followed by cooling during the 'rest' period between the peaks. It is therefore possible to use a high peak pulse power of a few hundred watts. The mean power is not increased, and in fact is usually reduced. The absorption and tissue ablation is maximal with very little lateral thermal spread. Thus, the tissue effects of the CO_2 laser are instantaneous – and can be described by the acronym WYSIWYG: what you see is what you get. The clinical relevance of this is that *each pulse* has enough energy to ensure the instantaneous and complete removal by vaporisation of any tissue it strikes. Thus, there is minimal residual heat in the tissue at the operation site, which could conduct this heat to the deeper tissues. The ultrapulse mode is used in skin resurfacing where the aim is to minimise the damage to the underlying tissue.

The tunable dye laser or pulsed dye laser (PDL)
The tunable dye laser contains a liquid dye. This dye is usually an organic substance and may be carcinogenic. Hence, care is required when changing it, and protective gloves must be worn. The emission, determined by the dye used, ranges between 400 and 700 nm. An optical pump, either a xenon arc flash lamp or an argon or copper vapour laser, provides the external power. The wavelengths of 577 and 585 nm are useful in dermatology for treating port wine stains. The tuneable dye laser is also used in photodynamic therapy (PDT) for cancer. The laser light at 630 nm is preferentially absorbed by a porphyrin photosensitiser with the production of cytotoxic singlet oxygen. Dye lasers can be difficult to operate reliably; therefore they are not used routinely. New solid-state lasers, with variable wavelengths, are likely to replace them.

The excimer (excited dimer) laser
Excimer lasers emit in UV wavelengths, with the two most common types being the argon fluoride (193 nm) and krypton fluoride (248 nm). The lasing medium is usually a gas. The tissue destruction is due to a photo-ablative process involving disruption of chemical bonds of organic compounds in the target tissues. Their use in medicine is mainly confined to corneal sculpting, as performed during laser-assisted in situ keratomeliusis (LASIK).

The semiconductor diode laser
The diode laser is a semiconductor electronic device that produces laser light by electrical stimulation of arrays of laser diodes. Semiconductor diode lasers have now replaced some of the older types of laser. They offer good reliability (in some cases maintenance-free) and are easy to transport. Their cooling and electrical power requirements are much less demanding.

The gallium arsenide is one such type, available in either a low power form for low level laser therapy, or a higher power form for laser coagulation and vaporisation. Solid-state lasers with intermediate power are used in PDT. Diode lasers are also often used in the emerging field of photo diagnosis. For otolaryngology applications, emission at 810 nm is an useful compromise, both for water and pigment absorption. The energy is transmitted through an optical fibre, and can be used in both the near contact and contact mode. In the contact mode, as the fibre touches the tissue, its tip heats, creating a thermal effect for performing incision, excision, and vaporisation with good haemostasis. The lateral thermal damage is said to range from 300-600 μm, depending on the power levels used. In the non-contact or free-beam mode, using a bare end or cooled fibre, the fibre is held a short distance from the tissue. The beam is well absorbed by melanin, which generates high temperatures at the tissue surface, and results in rapid vaporisation with underlying coagulation of up to a maximum of 3 mm.

The helium neon laser
The HeNe laser is a low power device with a visible red beam emission at 632.8 nm. At the heart of the HeNe laser is a glass tube filled with a mixture of helium and neon gas. The HeNe laser has been used for many years as a pointer. It is also superimposed onto the path of the invisible infrared beams of various other lasers (CO_2, Nd:YAG, Ho:YAG), in order to allow the operator to see where the invisible beam is going to strike when activated. The low power HeNe beam has also been used in wound healing and in the treatment of pain. The results are controversial. Solid-state lasers are now replacing the HeNe laser in modern laser systems.

The holmium:YAG laser
The Ho:YAG laser has a pulsed infrared output at 2.1 μm. It has excellent absorption in water-rich tissue. Its lasing medium is an yttrium aluminium garnet crystal doped with holmium, a rare earth element. The laser is excited by a xenon arc flash lamp. Its peak power output in the kilowatt range makes it suitable for use in arthroscopic surgery. In otolaryngology, it has been used in nasal surgery and for tonsillectomy. Its wavelength may be propagated through an optical fibre.

The potassium titanyl phosphate laser

The potassium titanyl phosphate (KTP) laser is a useful device that has been under-utilised. In fact, it contains an Nd:YAG laser, which is frequency-doubled by passing the beam through a KTP crystal. Doubling the frequency halves the wavelength (from 1064 to 532 nm). Its visible green light appears to be continuous, but is, in fact, rapidly pulsed. The beam is easily transmitted down an optical fibre, used with a micromanipulator attached to an operating microscope, or simply as a free hand. The tissue absorption characteristics are similar to those of the argon laser, but with short pulsed emissions of a few millisecods thus making it ideal for eradication of telangieactasia. The addition of the 'star pulse' mode gives high peak powers at an adjustable pulse rate.

The neodymium yttrium aluminium garnet laser

The Nd:YAG laser emits at 1064 nm. Due to its very high penetration, it is well suited for haemostasis by coagulation, but care must be taken to avoid the unintentional irradiation of any important structures in the vicinity. It is also capable of vaporising large volumes of tissue. The beam is delivered via an optical fibre. The penetration depth can be minimised by using a sculpted diamond sapphire tip attached to an optical fibre. Improvements in technology have meant that this laser can now be air-cooled.

Erbium:YAG laser

The short-pulsed Erbium:YAG (Er:YAG) laser operates in the invisible infrared at 2.94 µm. The pulse duration ranges from 100-300 msec with 0.05-1.0 Joules energy per pulse, delivering an average power of 0.25-14 watts. It is a fibre-transmissible laser which is most efficiently absorbed by water. The 25-watt (40 Hz) system can be combined with an optional scanner for quick and homogeneous treatment of larger skin areas. It is used for cutaneous resurfacing with milder cutaneous involvement, including photo-aging with mild photo-induced facial rhytides, mildly atrophic scars, and textural changes caused by fibrosis and dermatochalasis. The Er:YAG laser, because of its higher affinity for water-containing tissues, causes a much finer level of tissue ablation. Although erbium laser resurfacing results in decreased postoperative morbidity with a shorter recovery period, it is said not to provide the same degree of improvement in photodamaged skin as the CO_2 laser. Continued research in the field has already led to the development of longer-pulsed Er:YAG lasers, which offer a compromise between the CO_2 laser and the short-pulsed Er:YAG lasers in terms of clinical benefits while maintaining the safety profile of the traditional short-pulsed system. In addition, many surgeons now use a combination approach with the CO_2 and Er:YAG lasers in an effort to maximise collagen contraction in certain areas and limit postoperative morbidity.

8. Q-switching

Q-switching allows the electronic exposure of a very high power output for a short duration of just a few nanoseconds. The Q-switched Nd:YAG laser has been widely used in ophthalmology for posterior lens capsulotomy and also in dermatology for the removal of tattoos. The first working laser dating from 1960 used a synthetic ruby as the lasing material. The ruby laser which is used as a pulsed output, may be Q-switched to give a very short exposure, and is still in clinical use for the removal of tattoos.

9. Laser-tissue interactions

The effects of laser beams on the tissue depend on several factors, or parameters. Broadly speaking, these fall into the following categories:

- the active lasing medium in the laser tube
- the delivery system
- the beam parameters
- the power density on the tissue
- the absorption characteristics of the tissue
- the skill of the surgeon

With so many variables, it is obvious that the effects caused on the tissues by the various lasers are not strictly comparable. Nevertheless, within well-defined parameters, it is possible to obtain a broader understanding of these laser-tissue interactions.

10. The active lasing medium in the laser tube

The active medium is the very powerhouse of the laser light. The excitation of this medium results in emission of radiation, which is the laser light. The emission is largely a monochromatic pure wavelength, peculiar to the medium. The absorption of the wavelength by the tissue is also specific, and not gross. Thus, in water-rich tissue, there is a very high absorption of the CO_2 wavelength. The high water absorption coefficient of the CO_2, Ho:YAG and Er:YAG lasers makes them eminently suitable for work on soft tissue. Port wine stains and haemangiomas contain a high proportion of haemoglobin. These lesions need a wavelength with an affinity for haemoglobin, such as that of the KTP and argon lasers. The Nd:YAG laser, with its deep penetration and high tissue scatter, is useful for large vascular tumours. The wavelength-specific absorption characteristics of the laser should be taken into account as a first step when choosing the laser for a particular surgical application.

11. The delivery system

The delivery of the beam to the target tissue is undertaken in various ways. It is important to note that the method of delivery of energy may change the parameters and may not always correspond to the reading shown on the control panel.

11.1. Articulated arm

The emerging beam is transferred from the laser aperture in a hollow metal tube, usually known as an articulated arm, since it comprises several tubes joined together by knuckle joints. The joints contain internal mirrors, which reflect the laser beam. Provided perfect alignment is maintained, the beam passes down the centre of the articulated arm and emerges at the distal end of the arm. At this point, the beam is wide and has a low power density. It is then passed through a lens to focus to a fine spot with high power density.

The precision-engineered part of the laser de-vice is also extremely vulnerable. If one of the mirrors inside the arm loses its alignment, the laser cannot be used since the movement of the beam becomes somewhat erratic. Care should be taken to ensure that the arm is not jolted or jerked. Most commonly, any damage to the arm occurs during movement of the equipment between the storeroom and operating theatre. The laser should never be moved by tugging at the articulated arm. Particular care should be taken during its passage through any narrow doorways. Any realignment should be carried out only by the manufacturer.

Since most materials rapidly absorb laser radiation generated in the far infrared region, delivery of the beam to the target tissue is not without difficulty. This is true of the CO_2 laser, which cannot be transmitted via a flexible optical fibre. The beam from the articulated arm can be delivered to the operating site by attaching the arm to either a micromanipulator, a handpiece or a waveguide.

11.2. Micromanipulator delivery

The micromanipulator is a device consisting of a system of lenses and a mirror with a joystick attachment. It is attached to the microscope. The distal end of the articulated arm is connected to the micromanipulator. The operator holds the joystick like a paintbrush and manipulates the beam onto the operating site, not unlike an artist painting a picture. The reflecting mirror comes in various focal lengths. It is necessary to ensure that the focal length of the lens in the micromanipulator, and that of the objective of the microscope, are the same. This is an important point to emphasise to surgeons who are learning about the use of the laser. When the two focal lengths are matched, the beam, seen on the focused target through the microscope, is also focused.

11.3. Handpiece delivery

The beam is focused by the system of lenses and mirrors onto the handpiece at a fixed point some 2 cm from its emergence at the distal end. A guide probe extends from the end of the handpiece. When the tip of the guide probe is in contact with the tissue, the beam is focused sharply on the tissue.

11.4. Optical fibre delivery

The ability of certain wavelengths to pass through a flexible optical fibre makes them eminently suitable for endoscopic delivery systems. A fibre may be passed through the biopsy channel of a flexible endoscope, thus allowing delivery of laser radiation to internal organs by minimally invasive techniques. The fibre transmission is easily achievable for wavelengths of between 250 and 2500nm and for powers of up to 10kW. Within the fibre, there is a core of high refractive index glass surrounded by a thin cladding of lower refractive index glass or polymer. The laser radiation is transmitted along the core by internal reflection at the boundary between core and cladding (Fig. 4). The losses within the fibre are low (only a few percent), unless the fibre is curved tightly. Losses are higher where the laser beam enters and leaves the fibre. To couple the beam to the

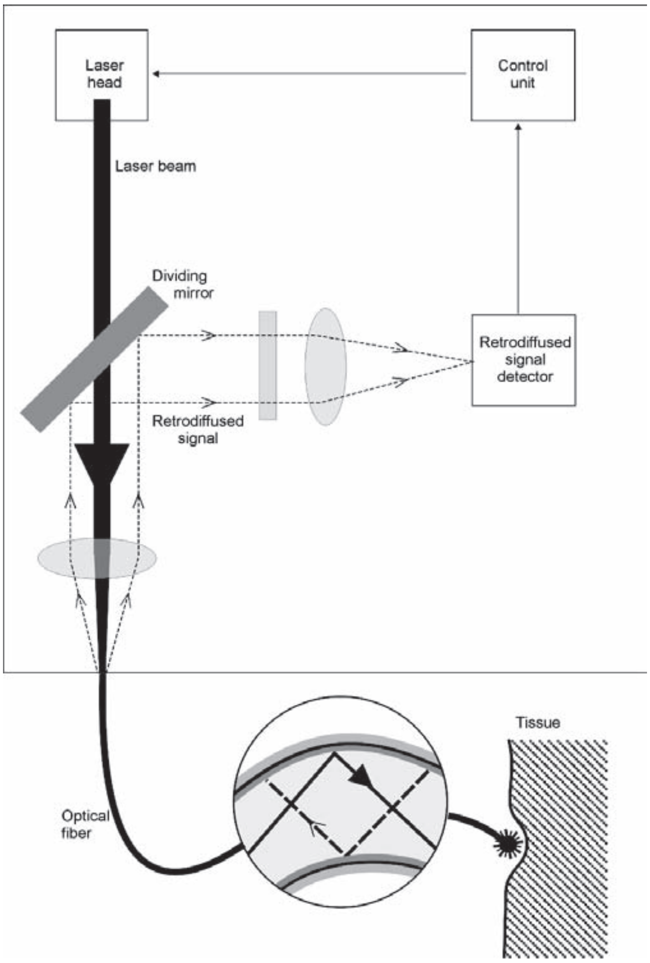


Fig. 4. The laser beam of most YAG lasers can be guided to the operating site via optical fibres. (Courtesy M. Remacle)

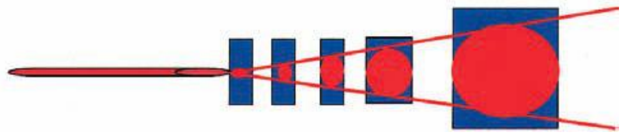


Fig. 5. Fibre transmission: divergent beam, spot size increases as the distance from the tip to target increases.

fibre, it is necessary to align the fibre very precisely in position, since the core may only be 100µm in diameter. If alignment is poor, the coupling end of the fibre may be damaged. The lens at the coupling end should also be handled with care. Any damage there could also lead to poor transmission. Some of the beam may be reflected back into the machine, and could damage it. A blast shield is provided to prevent this occurring. If the power of the beam through the fibre is poor, the entire fibre system, including the tip, coupling end lens and blast shield, should be examined for any possible damage.

Most lasers, such as the Nd:YAG, Ho:YAG, KTP and diode, with the important exception of the CO_2, are transmissible down a flexible optical fibre with a core diameter of 200, 400 or 600µm. The energy emerges at the distal end of the fibre and is maximally concentrated in a small spot. However, unlike the collimated beam, the emergent beam diverges by about 15-20°, the spot size gets progressively larger, and the power density diminishes proportionately (Fig. 5). Therefore, the power density incident on the tissue is largely dependant upon the distance of the target tissue from the tip of the fibre: 'tip to target distance'. When a greater vaporising power density is required, the tip must be held close to the tissue surface. On the other hand, the lesser power density required for haemostasis by coagulation can be delivered by simply drawing the tip away from the tissue (Fig. 6).

It is worth noting that the optical fibres are wavelength-specific and should only be used according to the manufacturers' instructions.

The fibre tip may be end-firing, or side-firing. Moreover, it may end in a sculpted or a sapphire tip. The sculpted or sapphire tips absorb the energy and heat up. When the tip is in close contact with the tissue, there is minimum or no scatter of energy, and any tissue effects are simply due to the conduction of heat between the tip and the tissue, much like conventional diathermy. In the near-contact mode, the tissue effects are governed by the beam parameters.

Contact mode

When the tip is in direct contact with the tissue, some of it may stick to the tip. Now, the energy is not transmitted due to selective absorption, but simply by heat conduction through the layers of tissue. There is a significant increase in the coagulation zone. In fact, diode laser energy is delivered in this way, by initially charring the tip of the fibre with tissue or a wooden tongue depressor. For example, the increased coagulation zone provides useful haemostasis with the diode laser in turbinate surgery. But it must be appreciated that a large coagulation zone results in increased inflammatory response, with the possibility of gross tissue destruction and secondary haemorrhage. During use, the tip of the laser fibre can easily become contaminated with tissue debris, which absorbs some of the laser energy. This means that less energy is being delivered to the target tissue. Also, the temperature at the tip

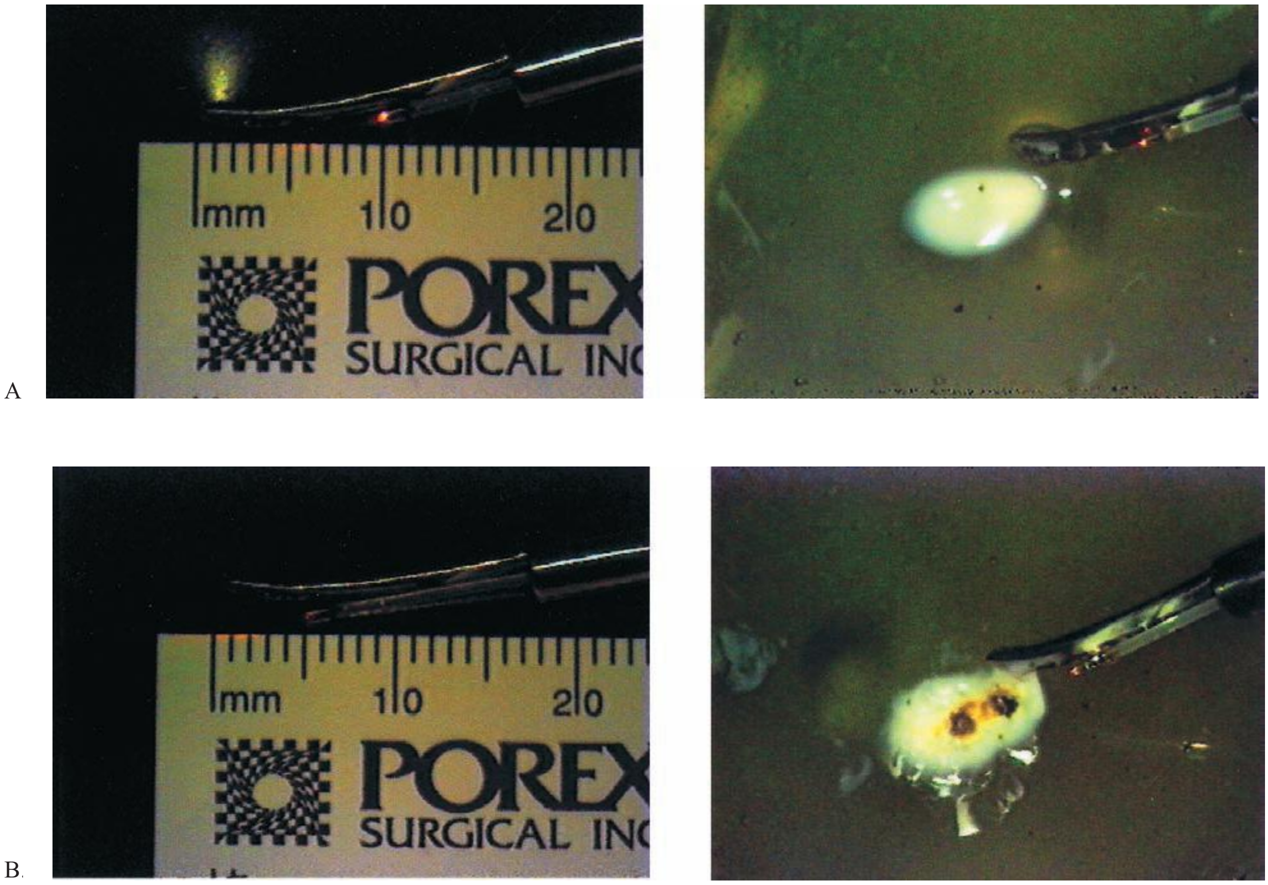


Fig. 6. Ho:YAG laser strikes on egg white, delivered through 365-µm fibre. Power density is more when the tip is nearer to the target. A. tip to target distance of 1 cm results in coagulation. B. Tip to target distance of 0.5 cm results in vaporisation and coagulation.

of the fibre may become very high and damage the fibre. To help prevent this, the fibre is cooled either by using it in liquid, or using compressed air for forced cooling. One common system uses two levels of air flow – a low-level stand-by and a higher rate of flow when the shutter is open and the laser is firing. It is a good idea to clean the tip regularly in saline.

Near-contact mode

The fibre-delivered energy can be used in the near-contact mode, in which the tip of the fibre is held 1 or 2 mm away from the target tissue. The beam passes through the air and then strikes the tissue. In the near-contact mode, the absorption characteristics of the wavelength being used govern the tissue effects. For example, if a vascular tissue such as the nasal turbinate is initially exposed to a KTP beam, it will be highly absorbed by the haemoglobin-containing tissue of the turbinate, such as the blood vessels. These will shrink and any vaporisation of the turbinate will then be bloodless.

Sapphire-tipped fibres

Sapphire-tipped fibres allow the surgeon to use the fibre in the contact mode and also provide a certain amount of tactile feedback, preferred by some. They also deliver high, localised power densities. The tip soon becomes coated with charred tissue, causing the temperature to rise to several hundred degrees. The tip is then used as a high-tech cauterising tool. There is a danger that the tip may become detached and, as a consequence, the technique is less popular than it once was. Sapphire tips are very expensive. A lower-cost alternative is to use sculptured fibres, which have been shaped to concentrate the laser beam into a small area (Fig. 7).

Side-firing fibres

The most commonly used fibre is an end-firing one. However, in certain procedures, it is useful to be able to fire the laser laterally while the fibre is

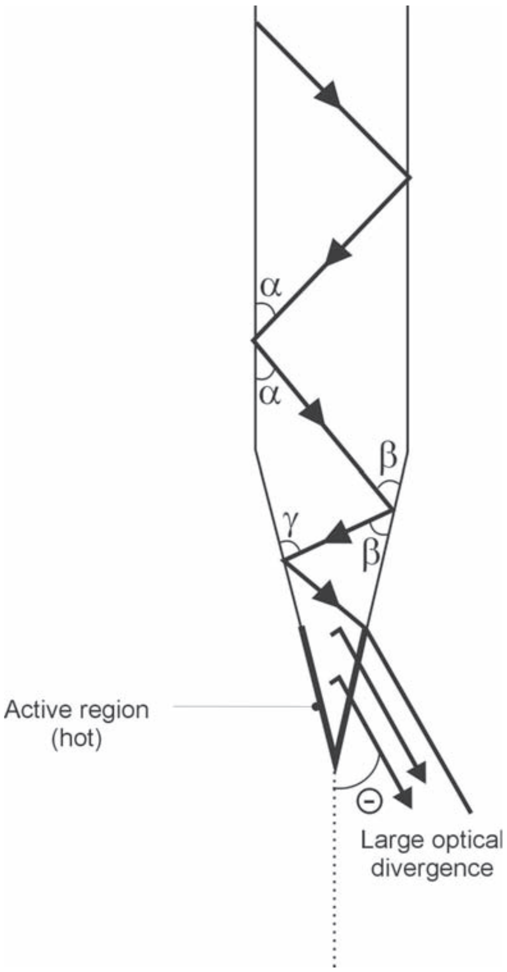


Fig. 7. Sculptured tip concentrates the laser beam into small area. (Courtesy M. Remacle)

sitting in the lumen. Therefore, special side-firing fibres have been developed for prostate treatment, and these perform extremely well at a relatively low power (20W).

The multiple use of fibres

It is possible for users to re-cleave simple bare fibres, thereby extending their useful life. Provided it is adequately sterilised, the same fibre can be used on several patients. However, some fibres are designed and marketed for single-use only. Though more convenient, disposable fibres increase the cost of a laser procedure. Potential buyers should inquire about the cost of the fibres and the number of times that they can be used. Some companies supply a fibre with ten single-use sterile sleeves which allows the fibre to be used ten times.

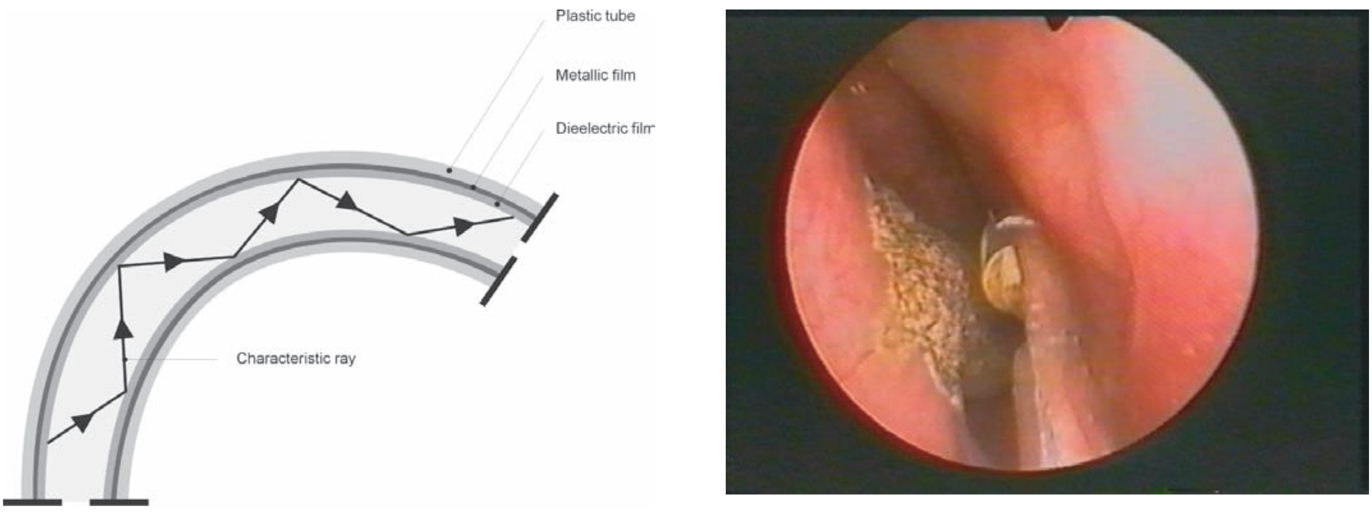
11.5. Rigid and flexible hollow waveguides

The CO_2 laser cannot be transmitted down a flexible optical fibre. Therefore, this useful wavelength cannot be used for treating structures situated deep in the cavities. For example, nasal applications with the free beam CO_2 laser are restricted to anterior nasal pathology. Moreover, there is a risk of inadvertent burning of the skin of the nasal alae. This problem has been addressed to a certain extent by the introduction of waveguides. A waveguide is a rigid, hollow channel, the interior surface of which is lined with a highly reflective ceramic or other material. Although 'rigid', it is possible to introduce a slight bend in the channel, while still retaining adequate transmission. Suitable small-diameter guides are available for use with endoscopes (Fig. 8). A waveguide is almost brought into contact with the tissue. A reflective metal surface at the end of the waveguide can direct the beam laterally, *e.g.*, for vaporisation of the mucosa of the turbinate. The view of the operating site is somewhat restricted due to the presence of the waveguide. Nevertheless, it provides a good alternative for taking the energy to tissues found in narrow cavities.

OmniGuide BeamPath flexible CO_2 laser system:
Conventional optical fibres consist of solid core material which guides laser light to the target tissue. Core material has a specific 'transparency window' which allows passage of only certain wavelengths while for other wavelengths, it is opaque. For example, silica has a transparency window which allows passage of wavelengths from 300 to 2000nm. KTP laser, which emits at 532 nm is therefore fibre-transmissible. CO_2 laser emits at 10,600nm, a wavelength which is well beyond the transparency window of silica and most other materials, and is not transmissible via conventional fibre. The CO_2 beam therefore must be used in free mode and delivered perpendicular to the tissue in line-of-sight of the operator.

OmniGuide, a US based company designed a hollow core fibre with a photonic band gap mirror lining. These hollow fibres are marketed as BeamPath™ fibres for use with CO_2 laser. Within each hollow fibre, alternating polymer and glass coating lines the core wall and transmits light.

Using BeamPath fibre, all the advantages of the CO_2 laser are available at the end of the tip of the fibre. BeamPath fibre is said to have given the op-



A.

B.

Fig. 8. Hollow waveguide. A.Hollow flexible waveguide for transmission of the CO_2 laser beam. B.Turbinate surgery with CO_2 laser beam delivered via hollo waveguide.

erator an added ability to remove tissue tangentially (non-linear), outside the usual perpendicular line-of-sight (linear) restriction while using the CO_2 laser. Free beam CO_2 laser cannot be used for subglottc or tracheal wall pathology since the vocal folds cover these areas beyond the linear line of fire of the free beam CO_2 laser. When used within a channel of the flexible bronchoscope,the BeamPath CO_2 fibre can tackle pathology in the subglottis or trachea without damage to the glottis. Further advantages are a tactile feedback, and cost effective 'office based' minimally invasive procedures. (Zeitel et al 2006).

Nevertheless, there is a trade off. The BeamPath fibres are currently expensive and the CO_2 laser machine needs to be adapted for the use of this fibre. KTP and pulse dye lasers are the obvious competitors. Although they do not have the properties of the CO_2 laser, they can be delivered through conventional fibres, with all the advantages of fibre delivery.

For further reading on the BeamPath fibre in clinical setting, please see the various chapters in the laryngeal section.

FiberLase CO_2 fibre

In September 2010, Lumenis Ltd introduced the new 2 metres long FiberLase CO_2 fibre, powered by the AcuPulse 40WG CO_2 Laser, for multi-application use.* AcuPulse 40WG CO_2 laser offers 40 watts of fibre input power. It has a diode aiming beam delivered to the tip of the FiberLase fiber allowing accurate targetting of the tissue being treated. The manufacturers also state that the FiberLase fiber has the lowest beam divergence of comparable devices. The combination of high power and low beam divergence result in faster treatment times and a more precise and consistent tissue effect.

The fibre is cleavable and the makers supply an optional dedicated tool kit. Cleaving of fibre tip is useful in case the tip performance deteriorates due to contact contamination by tissue sticking to the tip or, due to excessive carbon accumulation, during a single surgical procedure. Thus, since, the fibre is marketed for single use only, cleaving and using the fibre in another patient is not an option. This adds significantly to the revenue costs. For clinical experience of this new CO_2 laser fibre, see Chapter 59.

12. Beam parameters

The spot size of the beam determines the power density at any given power setting. For maximum ablation, high power delivered with a small spot size of a few hundred microns in diameter is necessary.

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* http://www.surgical.lumenis.com/acupulse40wg

Since the maximum energy is also concentrated at the focal point of the beam, the beam must be used fully focused on the target tissue. A defocused beam is useful when less power density is required, *e.g.*, for coagulation.

The smallest focused spot is associated with the gaussian mode, also known as the TEM00 mode. In the gaussian mode, the energy in the laser spot is bell-shaped, with energy concentration tapering towards the periphery of the beam. With a multimodal beam, the profile may be varied and may even turn out to be 'flat-top'. This is due to the combined effect of several modes. So where high power density (high power/small spot) is required, for precision work, the gaussian beam is the most desirable.

13. Power density on the tissue

When the laser energy leaves the laser head, it is virtually a parallel beam. It is brought into a sharp focus by a focusing lens. The power density is the power divided by the cross-sectional area of the beam. It is measured in watts per cm^2. The power density determines the rate of removal of the tissue. The beam must be perpendicular to the target tissue, so that the spot is sharply circular. A tangential strike will produce an oval spot with reduced power density.

14. Absorption characteristics of the tissue

Most tissue is not homogenous. The vascular content of some tissue may vary, due to chronic inflammation or the presence of necrotic material. Oedematous tissue contains much water, as in an enlarged allergic inferior turbinate, whereas a solid post-radiation lymphoedema will have a very low water content. The laser will give varying tissue effects in such situations.

15. Surgical skill

Like any other surgical instrument, the laser is also skill-dependant. There is a very definite learning curve associated with laser usage. For example, the penetration depth will be shallow if the laser beam is moved rapidly on the surface of the tissue. A slow moving beam will have longer exposure on the target tissue and, therefore, deeper penetration. An experienced surgeon will use various combinations of the parameters as well as his own skills to achieve the desired result.

16. Tissue effects

Despite the above variables, it is possible to identify the tissue effects common to most lasers. The energy in the laser beam is available as radiation, heat, and a photo-acoustic or mechanical form. But it is the thermal effect that is commonly used for surgical procedures. If we consider a single exposure of a short duration, say, 0.5 seconds, at a nominal 10-W power setting, using a CO_2 laser on a block of water-rich tissue, the following events, in varying degrees of combination, would be possible (Fig. 9).

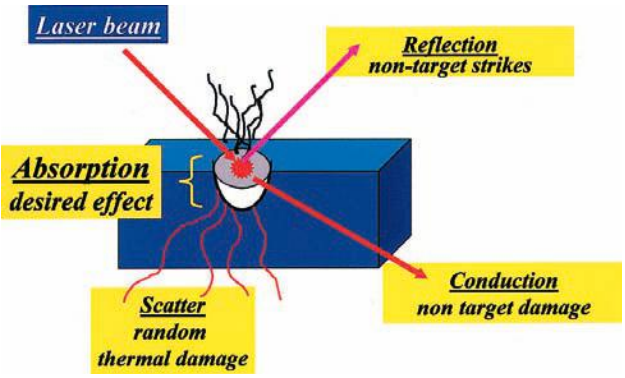


Fig. 9. Tissue interaction.

16.1. Reflection

Some of the energy will be reflected back from the surface of the tissue. Normally, such reflections are minimal due to high absorption of the energy by the tissue. However, polished metal instruments are used in the surgical field and should the beam strike surface of one of these instruments, significant reflection will occur. The intensity of the reflected beam will depend upon whether the reflective surface is concave or convex. In practice, the reflected beam is easily recognised since it is usually distorted and lacks the anticipated tissue effect. (Fig. 10). The reflected beam will only cause damage if it remains in focus over a distance. For practical purposes, the whole theatre is considered to be the hazard zone from the reflected beam, and is known as the 'nominal hazard zone'. All personnel working

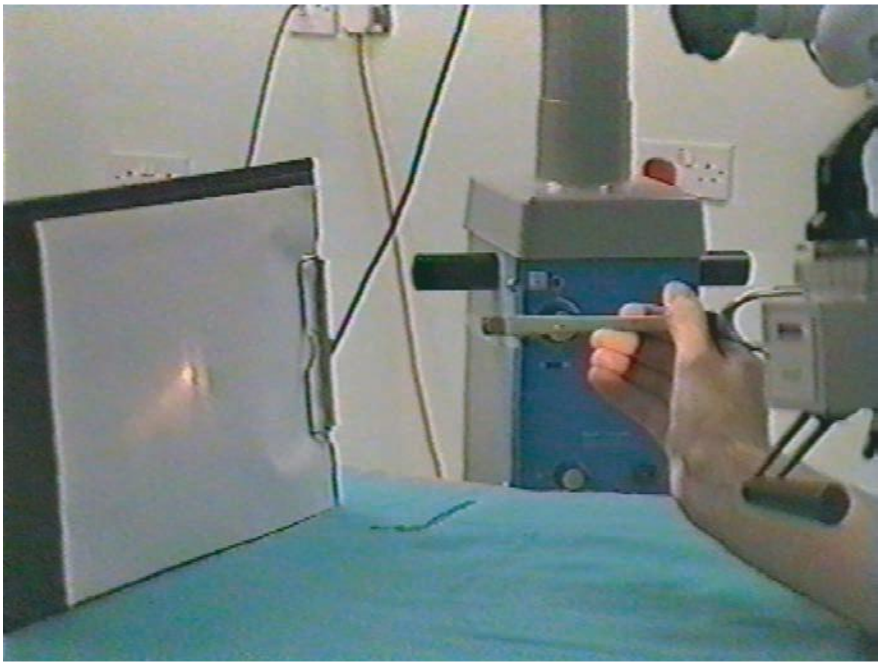


Fig. 10. Reflected beam is distorted and lacks anticipated tissue effect.

in the hazard zone are required to wear protective eyeglasses, specific to the laser being used.

During laryngoscopy, the beam may reflect from the inner wall of the laryngoscope. The laser spot on the tissue will be distorted and will have much less power density. Thus, it is necessary to ensure, particularly when using a laryngoscope with a narrow lumen, that the spot on the tissue comes directly from the beam and is not a reflection from the metal wall of the laryngoscope. A reflected beam can also prove hazardous if it strikes the flammable anaesthetic tube or its cuff.

16.2. Absorption

For any type of tissue effect, all or some of its components must absorb the laser energy. Apart from bone, all tissues are predominantly made up of water. The CO_2 wavelength is strongly absorbed by water and, therefore, it is not surprising that the CO_2 laser has been widely used for soft tissue work in a number of specialities. Apart from water, the other important constituents are pigments known as chromophores. These chromophores show high absorption to visible light and near-infrared radiation (Fig. 11). The retina contains melanin. The argon and KTP lasers emit in the visible spectrum, and thus are useful wavelengths for chromophore absorption in retinal and dermatology surgery. However, in otolaryngology, the power setting of these wavelengths is much higher. Since neither the cornea, aqueous humour, lens, nor vitreous humour of the eye absorb these wavelengths, they would be transmitted uninterruptedly to the retina, where they would form a hazard. Therefore, specific eyewear to filter the wavelength must be worn.

In stapes surgery, it has been argued that the use of the argon wavelength on the footplate may result in its inadvertent absorption by the stria vascularis, leading to sensorineural deafness. The experience of a number of workers has not supported this theoretical consideration. Moreover, it is thought that there would be enough beam divergence to reduce the power density by the time it comes to strike the vessels.

Absorption of the KTP and argon wavelength by haemoglobin has been accredited to help haemostasis. However, haemostasis also results from tissue shrinkage and collapse due to thermal effects of these wavelengths. Tissue ablation effects are diminished in the presence of bleeding, as the blood would absorb most of the energy, with inadequate levels remaining for tissue ablation. For example, if the KTP laser is used to vaporise the bone in choanal atresia, any blood that may be present in the nasal cavity will absorb most of the energy. The result is gross charring of the bone rather than vaporisation. It is necessary to control any bleeding and to remove

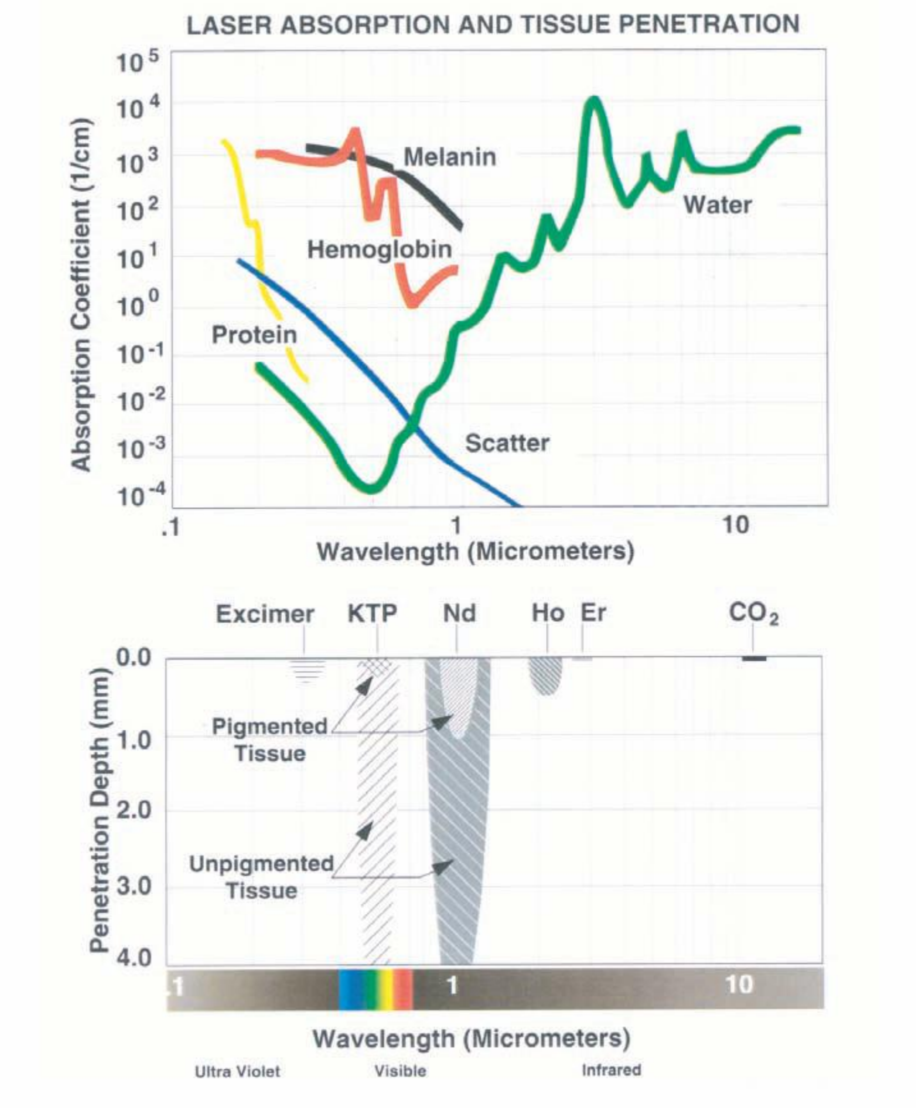


Fig. 11. Absorption of radiation energy by various chromophores and water in tissues. (Courtesy, Coherent Inc., Santa Clara, CA, USA)

any blood from the operating site when using the KTP or argon wavelength, for tissue ablation.

16.3. Photothermal effects

Following tissue absorption, the energy is converted into heat, the effects of which are known as photothermal effects. The thermal effect has several components (Fig. 12A & B). As the temperature rises beyond a certain level (approximately 55°C), the tissue will be irreversibly damaged with denaturation of protein and coagulation, invoking an inflammatory response. However, if the exposure continues, the tissue will suffer immediate thermal necrosis with consequent blistering. The necrotic tissue will slough off (or peel off from the blisters). During exposure, as the temperature continues to rise even further, both intra- and extracellular water boils at 100°C, and water vapour is formed. Then the cells explode and the cellular debris flies out with force. With sustained exposure, the temperature of the tissue continues to rise rapidly, resulting in charring at about 350°C. This is blackened carbon, which is often seen lining the crater. It should also be noted that, when solid particles cross the path of the beam, their temperature rises even further and they may glow. This incandescence may also be observed when the beam strikes blackened tissue.

Absorption length is defined as the depth of the tissue through which the laser is effectively completely absorbed. As the laser beam passes through tissue, the irradiance reduces exponentially. So, in

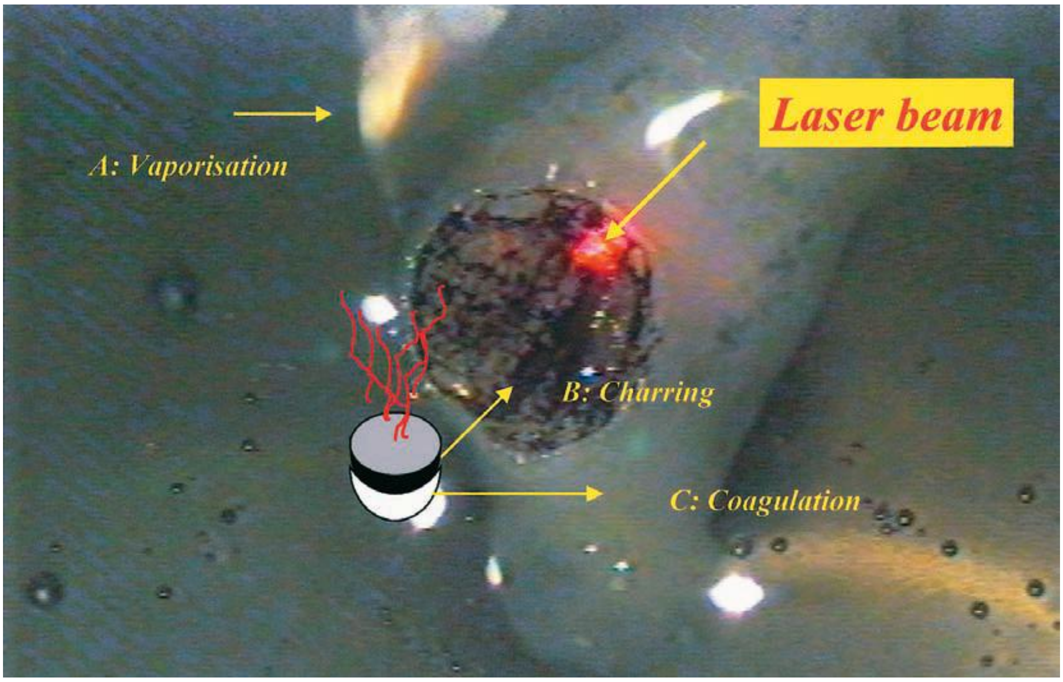


Fig. 12A. CO_2 laser absorption on egg white – 40 W, 1 second exposure.

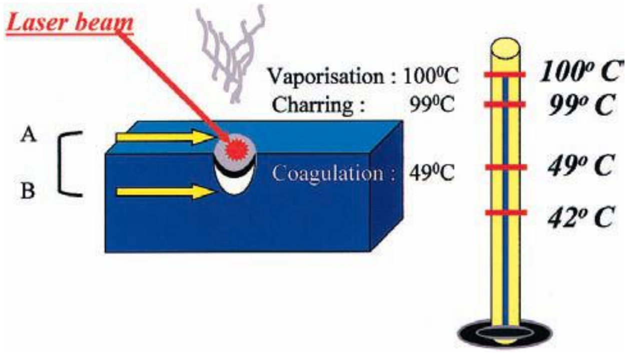


Fig. 12B. CO_2 laser tissue absorption A-B: absorption length.

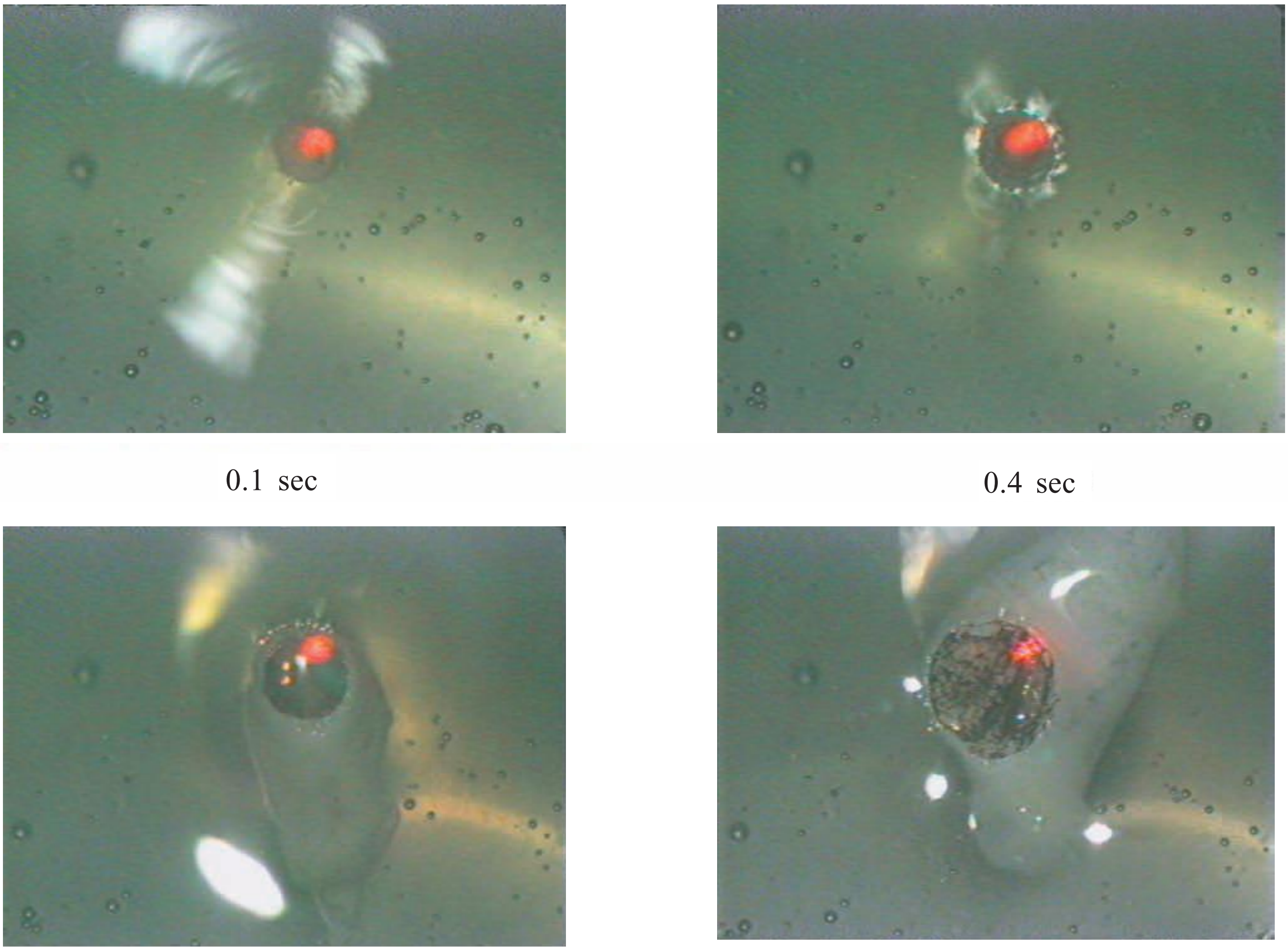
practice, the absorption length is usually taken to be the distance at which the irradiance is reduced to a given fraction of the incident irradiance. Different authors take this to be either 1/e (e is the base of the natural logarithm and equals 2.718) or 10%. Thus, depending on the definition being used, the absorption length is the distance at which the irradiance (power density) is down to about one-third or one-tenth of the level at the tissue surface. The whole absorption length will suffer the laser effect, although the effect will be greater at the surface. The tissue beyond the absorption length may also be affected because of the conduction of heat. This can be appreciated with a laser strike on transparent egg white: the conducted heat results in coagulation deep to the crater (Fig. 13). Penetration of the laser beam is synonymous with the absorption length.

16.4. Photoacoustic (or photomechanical) effects

Photoacoustic effects occur when an intense, high-power laser beam is focused on a small area, for a very short duration. With the Q-switched technique, the energy build-up takes place within the laser, followed by rapid release. For example, a Q-switched Nd:YAG laser with a typical output of only 20 mJ, is delivered in an incredibly short time – just 10 nsec. It is easy to work out the power levels with the equation:

Power (watts) = energy (Joules)/time (sec)

In this example, 20 mJ divided by 10 nsec gives an amazing 2 megawatts of power! Thus, the Qswitched Nd:YAG laser emits two million watts of power for the very short time period of 10 nsec. By exposing a small area to this intense power, an ionic state of matter, known as electrical plasma, is created. When the plasma collapses, a shock wave is produced, disrupting the tissue in close proximity. The laser photoacoustic effect is used in ophthalmology and lithotripsy.



0.1 sec

0.4 sec

0.75 sec

1.0 sec

Fig. 13. Effects of CO_2 laser strike at 40 W, 1 second, on egg white.

16.5. Photoablation

Photoablation is a process whereby a laser beam in the UV region is used to break down the molecular bonds. The energy contained in individual laser photons is sufficient to break the bond without a thermal effect. Photoablation is an extremely precise technique which is used to reshape the cornea for vision correction with an excimer laser.

16.6. Photochemical effects

Long exposures at low power density will not produce a photothermal reaction, but there may be a photochemical effect. This effect is seen when the laser wavelength matches the absorption characteristics of some chemical chains contained within the tissue. The most common example of the use of the photochemical effect is in photodynamic therapy (PDT), a technique whereby a tumour is sensitised with a photoactive drug. When light from a laser is directed at the tumour, a photochemical reaction takes place, leading to the production of cytotoxic singlet oxygen, causing cell death.

16.6.1. *The principles of photodynamic therapy*

In PDT, the tissues are sensitised by injecting a photosensitiser such as the haematoporphyrin derivative (HpD). Some very encouraging results have been reported, particularly in skin, bile duct and brain (Ibbotson *et al.*, 2004; Moseley *et al.*, 2006). Although in normal tissue the drug is metabolised within a few days, actively mitotic tissues retain the drug in higher concentrations. When the light of a suitable wavelength is delivered to the sensitised tissue, HpD in mitotic cells absorbs it in sufficient intensity to cause a momentary release of the singlet oxygen, cytotoxic to the cells. At most body sites, selective uptake is poor (3:1 or less), with the exception of the brain tissue, where concentration in tumour tissue is 10:1. Therefore, it is important to target the sensitised tissue accurately, in order to maximise the therapeutic effect on any malignant cells and to reduce the collateral damage to normal tissue.

PDT has a direct lethal action on cells, and probably on the cell membrane, but it also acts on blood vessels. Destruction of the tumour is due, at least in part, to destruction of the tumour vasculature.

PDT was initially carried out using HpD for both the diagnosis and therapy of malignant tumours. The active components of HpD are dihaematoporphyrin ethers and esters (DHE). A commercial preparation of DHE is available, known as Photofrin. New sensitisers, *e.g.*, benzoporphyrin derivatives and phthalocyanines, are being developed. Photofrin has a weak absorption peak at 630 nm, whereas the new sensitisers have absorption peaks at longer wavelengths with deeper penetration and destruction. Early investigators realised the clinical potential of a treatment which, theoretically, would deliver maximum damage to cancer cells. Encouraging reports appeared in the literature in the late 1970s and early 1980s (Dougherty, 1984). The introduction of fibre optic endoscopic laser irradiation allowed the technique to be applied to endobronchial lung cancer (Hayata *et al.*, 1982).

Although the sensitiser is concentrated in actively mitotic tissue, a lower concentration is still present in the normal tissue for four to six weeks. During this period, the patient remains sensitive to direct sunlight. Inadvertent exposure results in the blistering and burning of any exposed tissue, such as the skin of the hands and face.

Most treatments have been carried out using dye lasers, which can be tuned to the desired wavelength, *e.g.*, 630 nm. These devices were unreliable and needed ready access to good technical support. The recently available diode lasers can deliver light at the appropriate wavelength at sufficient power, and have virtually no maintenance requirements. Light emitting diodes (LEDs) are low cost, maintenance-free light sources that can be used for PDT treatment of skin lesions (Moseley 2009).

16.7. Conduction

Absorbed energy heats up the tissue. The heat starts to spread in all directions due to conduction. The conducted energy results in the thermal necrosis and coagulation seen in the bed of the ulcer crater. The conducted energy may also cause inadvertent damage to important underlying structures or to those in close proximity. Therefore, it is necessary to ensure that the depth of the thermal damage is minimised. This can be achieved in several ways. Use of superpulse at a low power setting is extremely effective for minimising the depth of thermal damage. Thus, any surgery on the free edge of the vocal cord is best undertaken using the superpulse mode, with intermittent exposure to allow a period of cooling.

The diffusion of heat within the tissue is known as thermal relaxation. The time taken to cover a given distance is proportional to the square of that distance. Thus, if it takes one second to raise the temperature of a 1-mm deep tissue to 70°C, then it will take four seconds to raise the temperature of a 2-mm deep tissue to the same 70°C. Heating of deeper tissue to any significant level can be minimised by the use of intermittent short exposure times.

Conduction of thermal energy by metal instruments in the vicinity of laser strikes can lead to burns in the non-target tissue. In an endonasal dacrocystorhinostomy (DCR) procedure, sufficient energy was conducted via a metal light pipe to cause a conjunctival burn.

16.8. Scatter

Some of the energy undergoes multiple internal reflections within the tissue, and scatters randomly, heating the tissues. The Nd:YAG wavelength, at 1064nm, displays considerable scatter within the tissue, causing deep thermal damage. The phenomenon of scatter can easily be demonstrated by pressing the laser pointer onto the tip of the finger in dark: the whole tip glows due to the extensive scatter of the red HeNe laser beam. The amount of scatter from the Nd:YAG beam can be minimised by using the sculpted tip of an optical fibre in close contact with the tissue.

16.9. Coagulation

In contrast to the conventional mechanical energy of the scalpel, the laser causes a zone of coagulation in the ulcer crater. In this respect, it resembles diathermy, the important difference being that the energy in diathermy lacks fine control. Coagulation occurs as a result of denaturation of the protein in the tissue.

If the main aim of surgery is to remove tissue as cleanly as possible, coagulation is an undesirable side-effect. Indeed, such is the case in phonosurgery, where preservation of the structures of the vocal cords is of paramount importance. However, coagulation is not always an undesired sideeffect, *e.g.*, in surgery for cancer of the tongue. A coagulum is a very effective haemostat. It also provides a protective barrier against infection. It seals off lymphatics and stops any metastatic spread of disease, and moreover, it forms scaffolding for the growth of epithelium.

The extent of the coagulation zone is dependent upon:

Wavelength: the Nd:YAG laser, at 1064 nm, in free beam mode, is widely scattered within the tissue. The absorbed scattered energy causes widespread coagulation. In the contact mode, the tip of the fibre heats up and the transfer of heat, by conduction rather than by scatter, takes place. Therefore, in this case, the zone of coagulation is small.

Thermal relaxation property of the tissue: generally, solid tissues retain heat longer than oedematous tissues. In the latter, thermal relaxation time is short since the energy is absorbed by water and the tissues shrivel, not unlike bacon in a frying pan. However, if the tissue is solid, absorption is slow, the heat continues to build up, and the thermal relaxation time is prolonged. In this event, there is greater heating and therefore greater conduction of heat within the tissue. Thus, the depth of coagulation will be greater. Thermal relaxation time is dependent on the volume of the absorbing tissue. As regards blood vessels, thermal relaxation time is 50 ms for capillaries, 500 ms for arterioles and venules, and 5 ms for large ecstatic vessels.

Exposure time: continuous exposure of the tissue to the laser beam results in heating up of the tissue and the thermal relaxation time is prolonged. There is increased conduction of heat to the deeper tissues, with a greater coagulation zone. Intermittent exposure allows cooling and shortens thermal relaxation time.

High power density: a high-power setting will result in the conduction of energy, if used in the continuous mode. In the superpulse mode, although the energy is delivered at high peak power, the average power is much less, and the depth of coagulation shallow.

Fluency: the surgeon controls the movement of the laser beam on the surface of the tissue. Slow movement will increase the depth of coagulation. In the management of vascular tumours, it is necessary to undertake preliminary coagulation before removing the lesion.

Ablation: strictly speaking, the term ablation (photoablation) refers to the process whereby a laser beam in the UV region breaks down the molecular bonds. In practice, ablation is loosely used to indicate loss of tissue by vaporisation. The main aim of surgery is the removal of tissue. The laser beam achieves this proficiently and bloodlessly. At the point of strike, the intra- and extracellular water boils, the cells burst, steam is released, and the solids form smoke or char, depending upon the level of energy. Loss of tissue creates an ulcer crater. Closely placed ulcer craters form an incision or excision line for the removal of tumours. This incision line can be deepened by continuous exposure of the tissue to the beam. Successive layers of tissue are thus vaporised. The depth of destruction at the point of cessation will be influenced by the factors described under ‘coagulation’.

Ablation and coagulation are directly opposing processes. An efficient ablator is a poor coagulator, as most energy is spent in ablation, with very little being left for conduction and coagulation. It is worth noting that lasers with long absorption depths cannot be expected to produce shallow damage zones. However, lasers with short absorption depths can be made to produce long absorption depths by using the various operator-controlled beam parameters described above.

Charring: charring is always a completely undesired side-effect. It is produced when there is insufficient ablation energy. The tissues lose water by desiccation. The charred tissue heats up beyond the boiling point of water (which is also the ablation point). The temperature of the tissue rises considerably, and with a greater coagulation zone, the heat is conducted deeper into the tissue. As the temperature rises even further, flares with the iridescence of charred particles occur as they re-cross the path of the beam and are heated even more. These particles can damage the delicate lining of the surrounding structures. In turbinate surgery, the heat from flying debris may devitalise the septal mucosa enough to cause thermal and avascular necrosis. If devitalisation takes place on both sides at the same point, the result is septal perforation.

The presence of even a thin layer of blood increases charring. It is therefore necessary to remove blood constantly and, as far as possible, to work in a blood-free field. If a significant layer of charring is formed, it should be removed by cleaning the surface with wet cottonoids.

Desiccated debris also wastes energy and slows down the progress of surgery. Any loose desiccated tissue is best removed with cottonoids or by suction, and surgery can then be continued.

Fluence: fluence is a measure of energy per unit area absorbed by a small volume of tissue. It takes account of scattered laser energy within the tissue. It should be remembered that, if a small volume within the tissue is being considered, the laser beam would come in from all sides. The rate at which the energy is deposited in the tissue is the fluence rate. It is measured as power density or irradiance by dividing the power of the beam by the area of the beam. Although the units are watts per cm², it is not the same as irradiance or power density since it includes radiation scattered into the volume of the tissue from all sides.

17. Laser classification

Class 1 devices are inherently safe, either because of their low output or by virtue of their engineering design, which prevents access to dangerous emissions.

Class 1M lasers are safe under reasonably foreseeable conditions provided optical instruments (mainly magnifiers) are not used. They are restricted to the wavelength range 302.5 to 4000 nm.

Class 2 lasers emit low-power radiation in the visible band (400-700 nm). Safety is normally afforded by the aversion responses, including the blink reflex. For a continuous output, the power limit is 1 mW. Particular care is necessary if sedatives are administered before laser surgery, as the aversion response may become sluggish.

Class 2M lasers are visible lasers which are safe provided no optical instruments (*e.g.* magnifiers) are used and the aversion response operates. They are restricted to the wavelength range 400 to 700 nm. The total power in the beam of a Class 2M laser may be much higher than a Class 2 laser but it will be either highly divergent or has a large diameter.

Class 3R lasers have accessible emissions exceeding the MPE level for 0.25 s exposures, if they are visible, or for 100 s exposures, if they are invisible. Their total output does not exceed the AEL for class 2 (visible) or class 1 (invisible) by more than a factor of five. The class does not include lasers emitting between 180 and 302.5nm. Eye injury is possible from intentional beam viewing.

Class 3B lasers have an upper limit of 0.5W for continuous output. Direct intra-beam viewing of these lasers is always hazardous, but viewing diffuse reflections is usually safe.

Class 4 lasers are high-risk devices with a power output exceeding those of Class 3B. Intra-beam viewing and specular (shiny) reflections are hazardous. Diffuse reflections can also pose a risk. The laser beam can also ignite flammable materials. They must be used with extreme and deliberate caution. The laser must always be treated with caution as a high-energy, potentially hazardous, operating device; it must never be used casually without due care. All operators should undergo training in the safe use of lasers.

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MCQ – 2. Laser biophysics

1. Laser is an acronym for
    a. Light Amplification by Stimulated Emission of Radioactivity
    b. Light Amplification by Stimulated Emission of Radiation
    c. Light Amplification by Simulated Emanation of Radiation
    d. Light Augmentation by Stimulated Emission of Radiation
    e. Light Amplification by Stirred Emission of Radiation

2. Laser beam maintains high intensity over a long distance because
    a. Laser produces very many photons
    b. Laser produces beam with wide divergence
    c. Laser produces beam with narrow divergence
    d. Laser produces beam with small degree of collimation
    e. Laser light is monochromatic

3. The device where the laser action takes place is called as
    a. Optical cavity
    b. Lasing medium
    c. Laser
    d. Laser beam
    e. Optical fibre

4. CO_2 laser is a laser of choice in otolaryngology because
    a. It can be used as free beam without obstructing fibre or hand piece delivery
    b. It is monochromatic, collimated & coherent
    c. It is a gas laser
    d. It is well absorbed in blood
    e. It is well absorbed by water

5. Lasers are named according to the lasing material they contain. Four types of material are used: solid, gas, liquid & semiconductors. Which type of material is used in Nd:YAG laser?
    a. Solid
    b. Gas
    c. Liquid
    d. Semiconductor

6. Which of the following is not optical fibre transmissible laser?
    a. Er:YAG
    b. Nd:YAG
    c. Argon
    d. KTP-532
    e. CO_2

7. Which of the following statements are correct?
    a. The argon laser was one of the first to be used for clinical applications
    b. CO_2 laser causes more lateral tissue damage than diode laser
    c. Photodiagnostic lasers are almost exclusively diode lasers
    d. Er:YAG laser is ideal for eradiation of telangieactasia
    e. CO_2 laser is ideal for debulking papilloma because it has a deep penetration in to the tissue

8. The effects of laser beams on the tissue depend on
    a. The surgical skill
    b. The beam parameters & the power density on the tissue
    c. The tissue chromophores
    d. The active lasing medium
    e. All of the above

9. Which of the following statement is correct?
    a. The KTP & Argon wavelengths are well absorbed by water
    b. The KTP & Argon lasers emit in the invisible spectrum
    c. The KTP & Argon are useful wavelengths for chromophore absorption in retinal and vascular surgery
    d. All of the above

Chapter 3

Risk management in laser technology: Primum non nocere – First do no harm

V. Oswal, H. Moseley and P. Smalley

1. Introduction

Physicians and healthcare workers should have two objectives when dealing with the patients. The first objective: 'Beneficence – doing good for the patient' is easily achieved following completion of their training. The second objective, 'Nonmaleficence – doing no harm' receives very little emphasis, if at all.

The Hippocratic oath enshrines the principle of 'Primum non nocere – first do no harm', or 'to abstain from doing harm'. The modern version of this aphorism is 'risk benefit issue' of a specific plan of treatment, where benefit outweighs the possible harm or risk, inherent to the proposed treatment.

Risk management may be regarded as a step forward towards the dynamic approach to the same principle, where risk and hazards are identified, and positive steps are taken to protect the patient from harm. An allocation of a separate chapter to cover risk management underscores the importance of active learning of this topic, alongside the disease managements.

2. Risk management in laser technology

While the use of lasers has raised a bar in sophistication of the modern day surgical practice, it has also introduced new hazards in the operating rooms. It is therefore incumbent upon the operating staff not only to learn the new skills, but also to be aware of potential risks and hazards and avoid them or minimise the risk.

Despite the many precautions taken in the operating room, there are regular although infrequent reports when harm has occurred to the patient. In an unsedated patient under local anaesthetic, patient may notice the harm and alert the team by shouting: for example, a skin burn from ignited drape or hair. In sedated patients, or in those under general anaesthesia, the patient input is not available, and the team needs to be extra vigilant.

In order to address this issue, a systematic approach has been established in a number of institutions under the banner of 'Risk Management'. Usage of lasers is spreading to office practices, clinics, and private enterprises. The burden of responsibility for safety has extended from hospital staff to the individual user, who may not have the benefit of appropriate or adequate educational resources.

3. Scope of this chapter

In this chapter, risk management is covered under several headings. Various hazards are identified and their mechanism is described in detail. Their potential injurious effects are covered, followed by methods of avoiding or minimising them. In the event that a hazard does become a reality, methods of managing the risk are described.

Finally, emphasis is placed on training and credentialing so that the incidences of hazards are minimised to achieve maximum safety with optimum surgical outcome. Although the book is primarily written for lasers in ENT, risk management has re-

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ceived a more general treatment for the benefit of other health professionals who are required to work in various disciplines using lasers. In particular, surgical fire is not restricted to laser; it can frequently result from use of electrosurgical units (ESU). Since all surgical fires have dreadful consequence irrespective of their origin, they need to be avoided.

Existing regulatory and non-regulatory requirements of reporting hazardous incidents are identified. A brief description of regulatory bodies of some countries is included. The coverage is extensive but, of necessity, not exhaustive. Furthermore, as the laser usage spreads globally, country-specific regulations may be different. The prospective reader is advised to log on the relevant website to update their knowledge on this topic. Laser regulations and guidelines may be found through such national or regional agencies as: ministry of health, bureau of radiation safety, occupational health and safety, and medical or nursing professional licensure bodies.

Safe use of lasers requires a variety of human and fiscal resources. Knowledge is an effective tool for minimising hazards and risks. Initial and continuing training requires staff time and local or regional training facility where laser related regulatory literature is available. In common with other equipment in clinical practice, lasers require regular in-house maintenance for its safe and efficient operation. In certain cases, a more specific maintenance or repair may have to be carried out by the manufacturers which may mean that the laser is out of action for some time. A Laser Protection Adviser (LPA) or Laser Safety Officer (LSO), who is knowledgeable in the evaluation of laser hazards, should be appointed. The LPA should ensure that suitable Local Rules are in place to control the safe use of the laser. A Laser Protection Supervisor (LPS) should be appointed to ensure that the Local Rules are implemented. A procedure of reporting of untoward incidents should be in place. Knowledge is an effective tool for minimising hazards and risks.

However, safety procedures are time consuming and there is an unwitting tendency to short cuts, complacency and human errors. Moseley (2004) identified operator error as the major factor (67%) in patient harm during 12 laser procedures.

For an in-depth understanding of laser safety, the reader is referred to Moseley & Davies (2003).

4. Laser science

The laser beam is an intense source of optical radiation which, when absorbed by tissue, can be converted into heat. Some surgical lasers such as the CO_2 produce *invisible* infrared radiation and pose additional beam hazards.

Conventional cold surgical instruments work mechanically by cutting tissues. Their effects are immediately visible and do not spread beyond the site of the operation. Diathermy devices deliver electrosurgical energy on tissue, through predetermined pathways of least resistance, creating inconsistent but highly effective tissue effects for controlling bleeding. In contrast, laser radiation produces *biological* effect in the tissue. Each laser wavelength-produces a controllable, reproducible, and target specific interaction which is dependent on the absorption target in the tissue. However, each laser also has a collateral effect that may be unintended. A thorough understanding of laser science enables a clinician to assess the risks and hazards of the laser to be used, and therefore, he or she can determine what safety precautions should be taken, to protect both staff and patients. The study of laser science should include but not be limited to:

- Laser beam, its production and characteristics
- Delivery systems and instrumentation
- Beam parameters
- Tissue interactions
- Types of lasers currently in use in ENT

These topics are covered in various chapters under appropriate headings and will not be repeated here.

5. Why lasers are hazardous

5.1. Laser usage introduces two kinds of hazards:

- Beam-related hazards

Beam-related hazards result from direct strike of the beam on tissue as well as non-tissue such as the endotracheal tube (ET). For example, unintentional beam strike on skin can result in skin burn. A strike on an ET tube can result in an airway fire.

- Non-beam hazards

The non-beam hazards are caused by electrical hazard, equipment failure, or malfunction, *e.g.*, a leaking fibre due to damaged cladding.

5.2. Hazards in laser surgery arise for the following reasons:

- Laser energy is hot

Surgical laser energy is ‘hot’ energy (as compared against knife energy which is cold energy). A strike on non-target such as unprotected skin can result in burn. A strike on paper or dry linen drapes can result in ignition and fire. A strike on an ET tube may result in serious injury to the airway and may even be fatal. A strike on flammable material such as swabs, plastic tubes, catheters etc can result in fire. A stray beam (*e.g.*, a damaged fibre) may inadvertently enter the unprotected eye and can cause corneal or retinal burn.

- Laser energy penetrates

Some laser wavelengths penetrate within the tissue, beyond the site of operation and can cause unintended damage to the deeper normal tissue. Some laser wavelengths (*e.g.*, He:Ne beam from pointers) entering the eye, can be absorbed in the fluids of the tear layer and cornea, causing superficial corneal burn. However, wavelengths which are absorbed by haemoglobin can travel through the structures of the eye, and can be refocused by the lens. The resultant increased power density, which is then transmitted to the absorbing haemoglobin in the retina, can cause a retinal burn, and the potential for permanent injury to central vision.

- Laser strike on tissue produces plume

When a cutting laser beam is used to destroy tissue, a plume escapes from the operation site. The plume is known to contain bacteria, gases, virus, and carbon, and can pose a health hazard for anyone who is exposed to it.

5.3. Laser classification

Based on the degree of potential damage, lasers are labelled with a safety classification. At one end of the classification are Class 1 lasers which are inherently safe since they are either of very low power or are encased, *e.g.*, lasers in DVD and CD players. They pose no hazard to the user. At the other end are Class 4 lasers which operate at greater than 500 mW energy and can cause damage to unprotected eye or skin and are capable of igniting flammable material in the presence of oxidising agent such as oxygen. All surgical lasers used in ENT belong to Class 3b or Class 4. The safety standards that should be followed are determined by the classification. See Chapter 2 for detail classification.

It is clear that some lasers are capable of causing damage at some distance from the laser beam because the beam can be fired through the air. This means that theatre staff may be at risk even though they are standing several metres away from the laser, which is unlike any other instrument used in the theatre. Laser risk management is thus an integral part of laser usage and any potential user must be as competent in managing the risk as he or she is competent in the use of the laser for a surgical procedure. The various potential hazards and their management are described below.

6. Eye injury

The eye is the most sensitive organ to light. Since the laser is just another form of light, eye is always going to be a ‘natural’ target organ for the laser (Fig. 1).

Once this fact is appreciated, it is easy to understand that eye must be protected from laser light except the one which is intended to enter the eye for therapeutic purposes.

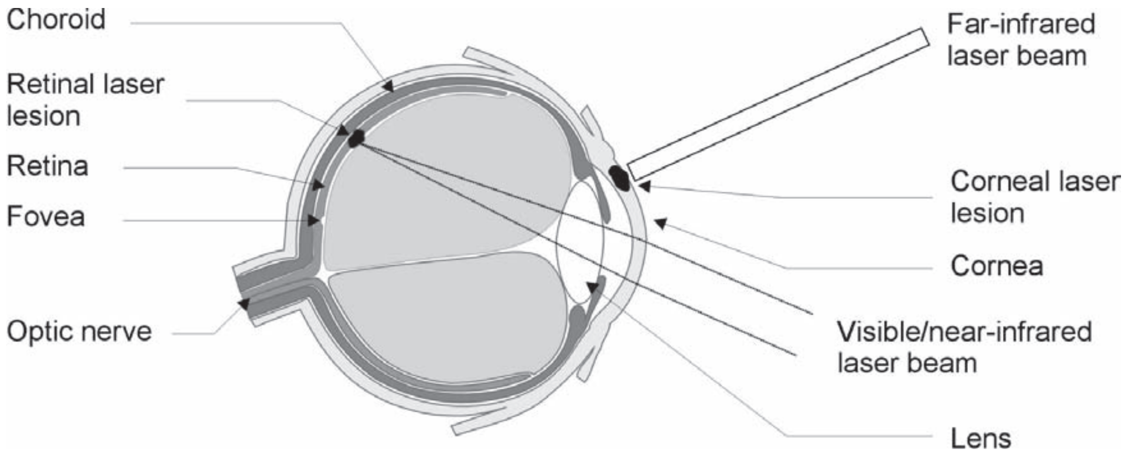

Fig. 1. Effects of exposure of eye to various wavelengths. The CO_2 laser wavelength is absorbed totally by cornea and suffers damage. The near-infrared YAG beam and the visible beams, such as the argon and KTP, are transmitted through the eye to the retina where, if irradiance is powerful enough, permanent damage results. (Courtesy M. Remacle)

6.1. Source of the damaging laser beam

In the operational mode, there are two ways that unintended eye exposure can occur. A beam falling on a shiny surface may be reflected back in to the room in sufficient power and inadvertently enter the eye. Reflected beam from a convex surface is divergent and thus loses power density within a short distance. A reflected beam from a concave surface will converge further and will be potentially damaging.

Another source of a stray beam is leaking fibre.

6.2. The wavelength

CO_2, Er:YAG, Ho:YAG and excimer wavelengths are absorbed by water in significant amount. The front of the eye, including cornea is the damage zone of the eye for these wavelengths. All other wavelengths will pass through the clear part of the eye and cause retinal damage.

6.3. The focusing power of the eye

Any wavelength which is not absorbed by water in the front of the eye will be transmitted through to the retina. In passing through the eye, the laser beam is focussed down to a small spot on the retina. This is the normal focusing property of the eye. Most of the focusing power occurs in the cornea with additional focusing taking place in the lens. This has the effect of increasing the intensity of the light by a factor of 10,000. A laser beam focused on the retina is capable of causing permanent damage and potentially sight-threatening.

6.4. Eye protection

6.4.1. Natural protection

The aversion response provides natural protection to bright light. The blink response, which is part of the aversion response, causes the eye to blink and this takes about 0.25s. This can provide protection from continuous beams provided the power is not too high. However, high power pulsed beams can inflict damage quicker than the blink response. It is also important to realise that the aversion response only applies to visible beams, *i.e.*, beams that can be seen. Many lasers used in ENT produce invisible beams, such CO_2 and Ho:YAG. The aversion response provides no protection against the damage that can be inflicted on the eye by these beams. The eye therefore must be protected with appropriate eyewear.

6.4.2. Protective eyewear

Protective glasses have lenses that reduce the hazard of emitted laser energy, and thereby help to

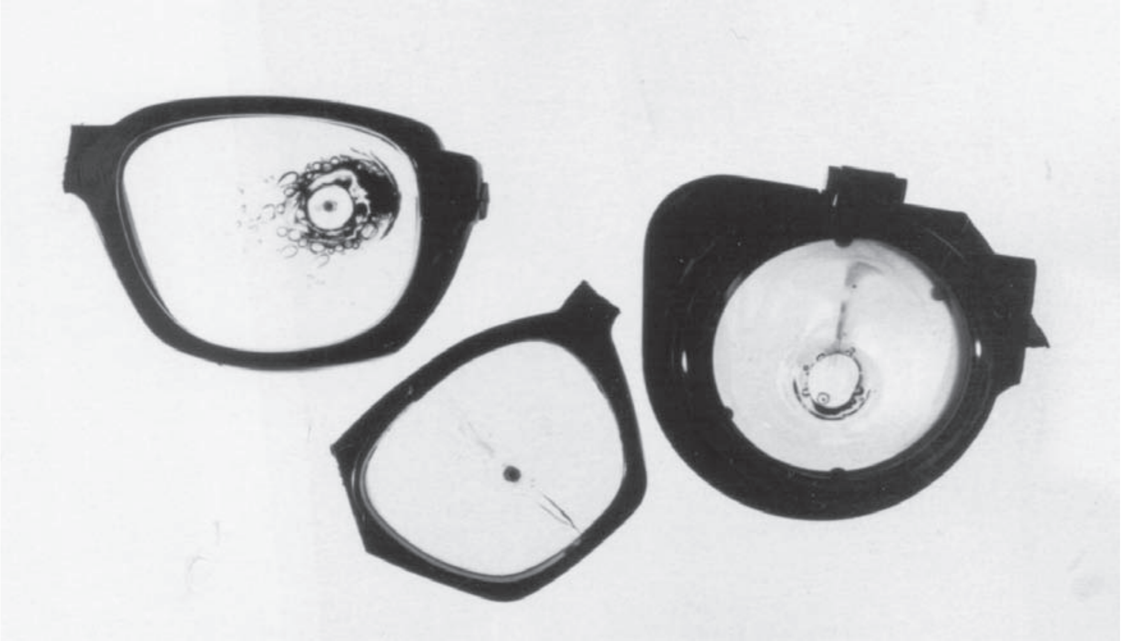

Fig. 2. Laser goggles burnt through after exposure to 20 W CO_2 laser radiation.

reduce the risk from accidental exposure to the laser beam. Each laser emits at a specific wavelength and therefore, each eyewear is specific to that particular laser. Eyewear is thus not interchangeable and a selection to cover all the lasers in use must be available to everyone entering the Nominal Hazard Zone (see below).

When an operating microscope is used and the CO_2 laser is delivered through a coupler, the optical lenses of the microscope will protect the operator who does not need to wear additional eyewear. When using a laser with a fiberoptic delivery system, a specific eye safety filter must be installed in the microscope, to protect the viewer, and anyone viewing through an attached viewing scope (teaching tube or monocular tube), must wear protective eyewear.

Prescription glasses cannot afford adequate protection since they do not provide a tight fit, have no peripheral protection, and they have not been tested and labelled according to the international standards required of safety eyewear manufacturers. However, it should be noted that laser goggles act by absorption and so the laser beam will burn through the goggles if their damage threshold is exceeded.

For further reading, please see Chapter 4.

6.4.3. Protecting the patient

When operating in the head and neck area, patient's eyes are lubricated with a water soluble lubricant; eyelids are taped, padded, and then covered with either protective eyewear, or a damp cloth drape. When operating under local anaesthetic, wavelength specific goggles, or periorbital eyewear, can provide adequate protection. When operating near eyes, anodised metal corneal shields should be used to protect cornea and conjunctiva.

7. Surgical fire and thermal injury

In the United States, there are approximately 2,260 reported hospital fires per year (Duensing *et al.*, 1997), resulting in about one death and 130 injuries. Of these, between 20 and 30 occur in the operating room (Federal Emergency Management Agency, 1993). According to ECRI, (reported in 2007) 44 percent of operating room fires occur during head, face, neck, or chest surgery, when electrical surgical tools are closest to the oxygen the patient is breathing.

Right at the outset, it should be clearly understood that the operating theatre is an ideal site for ignition and fire. Theatre environment of oxygen, heat and fuel provides a perfect environment for that well-known triangle. Different theatre personnel have responsibilities for each part of the fire triangle: igniters used by surgeons, fuel, managed by nursing staff, and oxidising agents controlled and monitored by anaesthesia staff. Surgical fires can result from electrosurgical units as well as lasers. Aly *et al.* (1991) reported electrosurgery-induced endotracheal tube ignition with airway burn during tracheostomy. Fires resulting from both igniters are considered in the following paragraphs.

7.1. Igniters

Igniters which initiate the fire are readily available, and liberally used. These mainly consist of electrosurgical units and laser. Electrical equipment, foot switches, drill motors, bulbs etc. are also to be considered as potential fire igniters since they may produce sparks. However, they are rarely implicated in surgical fires.

Since potential igniters are aimed, activated and used for a surgical procedure on the patient, it is hardly surprising that surgical fires usually occur on or in the patient. It follows that the potential victim is the patient. The operating staff, actively involved in the procedure, are rarely injured and the equipment is rarely damaged by fire. It is usually the patient who bears the major brunt of this unpleasant event. Not uncommonly, the injury is severe, and may be fatal. Human and economic toll is disastrous. What is surprising is that all surgical fires are totally preventable, but in spite of this, surgical fire incidents continue to occur regularly.

Hot gases and smoke emanating from burning tissue form an unwitting source of ignition of the flammable material, particularly in the presence of oxidising agent such as oxygen. The tissue fragment may turn in to an exploding ember and carried to flammable material such as an unprotected cuff. The resultant fire can be severe. A reflected beam may have sufficient energy to induce ignition. Finally, even after inactivation of laser beam the tip of the fibre may retain enough heat to cause fire in flammable material.

When diathermy is used to control bleeding in a fatty tissue, the spark is more intense.

7.2. Flammable material

Disposable drapes are treated with flame-retardant materials; they are less expensive and more water resistant. However, when they do ignite, they burn more readily. The fire also spreads more rapidly. Cotton drapes, particularly if they are saturated with a run off of an alcohol-based skin prep such as chlorhexidine (Chorhexidine 0.5% in alcohol 70%), will also flame. Alcohol burns invisibly at 850 °C. Betadine solution is flammable at a higher temperature. Aqueous-based skin preps will also ignite, but at a higher temperature, so they provide a relatively safer option.

Suction catheters, feeding tube, tracheostomy tube, swabs, pledgets, cottonoids are all made of flammable material and will ignite, and also sustain fire.

Methane gas in the flatus is highly combustible and will ignite during laser procedure for prostate, gynaecological, or rectal procedures.

Cladding of an optical fibre, if not removed over a sufficient length, say a centimetre, can also heat up and ignite.

Anaesthetic tube is a potent and sometimes lethal source of fire since the airway is shared by the anaesthetist as well as laser surgeon. If ignited, a standard polyvinylchloride (PVC) endotracheal tube specifically poses a life-threatening hazard. It will ignite in less than half a second of a CO_2 laser strike. Plastic is a mixture of hydrocarbons with various other elements added to create its special properties for use as an anaesthetic tube. When ignited, it releases toxic smoke, containing hydrogen chloride, hydrogen fluoride, cyanide, mustard gas, phenol, aldehydes, and other complex hydrocarbons. Patient is asphyxiated, and the lungs, filled with these toxic gases prove fatal long before the burn of the tracheal wall from a flaming tube.

Facial hair, particularly moustache and beard, can burn. They should be covered with water soluble lubricant such as K-Y Jelly.

7.3. Oxidising agent

Airway contains high concentration of oxygen used to ventilate the patient. Nitrous oxide used to anaesthetise the patient is also present in high concentration. When heated, nitrous oxide will release its oxygen component, thus increasing oxygen concentration in the airway. Therefore, in the presence of intense heat produced by the laser beam in the airway, both these gases are oxidising agents and support combustion. Their combined concentration within an anatomical area will govern the energy needed to combust and also ferocity of the fire, once established.

When the patient is intubated, the concentration of these gases in the upper airway is minimal due to inflated cuff. The concentration in the lower airway *below* the level of the cuff is high. However, should there be a leak around the cuff; the concentration in the upper airway will also be high.

In an intubated patient, a tracheostomy incision is usually taken below the level of the cuff. The concentration of the oxidising agents here is high. If an incision is taken on the trachea with cutting diathermy, there is a danger that the temperature on the endotracheal tube will increase sufficiently and fire will ensue in the presence of high concentration of oxidising agents at this site. Such incidents have been reported (PA PSRS, 2007).

When a patient is given oxygen through a nasal cannula, there may be enough concentration of oxygen in the vicinity of head and neck and pose a fire hazard. This is particularly so if the drapes and towels are intentionally or unintentionally tented over the oxygen supply to the patient.

7.4. Ignition

In a surgical field where tissue is being removed with ESU or laser beam, the temperature rises to several hundred degrees centigrade. Flying incandescent charred tissue provides igniter which raises the temperature of the adjoining fuel (such as plastic tracheostomy tube) in an oxygen-enriched atmosphere. Even a modest rise in temperature will accelerate the oxidation process of the fuel, and ignition takes place. Unlike the electrosurgical unit, the laser has the added risk that it can cause ignition over a considerable distance as it travels within the patient to its intended target site. The rise in temperature is rapid when laser is used and the ignition is almost instantaneous.

7.5. Fire

Most fuels burn in gaseous state. The heat turns solids and liquids in to vapours. Vaporised fuel combines with oxygen and ignites. Continuing production of vapours establishes the fire. Higher concentration of oxygen provides increased amount for oxidation and the fire burns faster and hotter and quickly spreads to the surrounding area. A plastic anaesthetic tube burns in 100% oxygen so furiously that there is blow-torch combustion of the whole tube with a loud bang, in less than half a second. It therefore makes sense to use smaller concentration of oxygen where possible. As already stated, in the presence of heat, nitrous oxide releases its oxygen, thus increasing the overall oxygen concentration. A mixture of oxygen and nitrous oxide, commonly used to ventilate and anaesthetise patient results in a potential oxygen enriched atmosphere in the presence of heat.

7.6. Spread of fire

Once established, fire quickly spreads in oxygen-enriched atmosphere until all the fuel is consumed. The spread of fire can be curtailed by dissociation of fuel and oxygen combination. Fuel is relatively cumbersome to remove. Oxygen can be withdrawn quickly by dousing the fire with wet towels, drape, etc. For fires in the head-and-neck region and in the airway, the supply from the anaesthetic machine is immediately turned off.

8. Prevention of surgical fire and management strategy

8.1. The fire triangle

There are three distinct groups of theatre staff who control their side of the fire triangle. Nurses and technicians have control of the fuel, the operating surgeons have control of the igniters and the anaesthetic team controls the oxidising agent. Each group is therefore responsible to ensure that their side of the triangle does not meet the others' sides. But in addition, each group also has a corporate responsibility to oversee others' activities, communicate intentions, agree to a protocol and thus avoid surgical fires.

8.2. The heat source

Most fires start because the heat source was used without due consideration to the presence of fuel in the oxygen-enriched environment. Oxygen is ubiquitously present in the air, and cannot be removed! The operator must therefore exercise the highest degree of vigilance to notice the presence of fuel and take appropriate steps to safeguard its ignition. Further, it is essential to know and strictly adhere to, the drying times for all solutions and skin preparations, before allowing an energy based device, to be activated in the surgical field.

8.3. The fuel

Damp towels, drapes, and wet pledgets will protect most potential fuel from coming in contact with heat. Aqueous-based skin preps, jelly for hair and use of non-flammable drapes will further resist ignition of fuel.

8.4. Oxidising agent

Use of air rather than oxygen, diluting oxygen concentration by mixing with inert gas such as helium and ensuring that there is no escape of oxygen around face masks or cuffs etc., will minimise oxygen enrichment of the operating environment. Particular attention is necessary to avoid tenting of drapes and towels over the tubing supplying the oxygen.

The Emergency Care Research Institute (ECRI) has issued guidelines in October 2010, following a death of a patient due to saturation of oxygen under drapes. They recommend that the airway be secured for oxygen delivery. Open oxygen delivery must be taken only under exceptional circumstances. In the latter event, the oxygen saturation should be minimal to maintain adequate blood oxygen saturation.

8.5. Fire extinguisher

A surgical facility where high-power class 4 lasers are used should have a suitable fire extinguisher, such as Carbon dioxide extinguisher, just outside the facility to complete the preparedness for eventuality. The CO_2 extinguisher will effectively control and douse fires involving drapes, plastic, paper drapes, flammable liquids and electrically energised fires, without contaminating the facility.

(Current standards require an electrical equipment fire extinguisher outside any room where any electrical equipment is used – not just class 4 lasers)

9. Airway fire

Any fire event occurring on the patient's body is serious, but rarely fatal since they are on the surface and therefore easier and quicker to control. However, fire in the airway is in an oxygen-enriched confined space, is furious from the onset and has a potential for a fatal outcome.

The Emergency Care Research Institute report suggests that, of all the surgical fires, approximately 21% occur in the airway (ECRI, 2006). Tracheal tubes, if not made of laser-resistant material, will ignite due to flares from burning tissue or incandescent smoke or direct beam strike. Chapter 6 covers a detailed discussion on the topic of airway fire and alternative anaesthetic techniques to minimise or remove the hazard altogether from the operating site. However, below is a brief summary for a quick reference.

9.1. Minimising the risk of airway fire

Bullet points which will minimise potential to airway fire are:

- Use a laser-resistant tracheal tube, specifically tested for safety with the wavelength of laser to be used, and within the intended surgical parameters, and follow manufacturers' instructions.
- Use a lower concentration of oxygen.
- Use laser in intermittent exposure mode to allow cooling of tissue between strikes.
- Activate the laser when guiding beam or tip of the delivery fibre is away from the tube.
- Fill the cuff with methylene blue and saline. Its appearance outside the cuff will immediately indicate its puncture. Remove and replace the tube.
- Use wet cottonoids to protect the cuff. Theatre staff must count these in and out of the field, and add the correct count to the surgical count sheet.
- Remove at least one centimetre of cladding from the optical fibre used to deliver the laser beam.
- When using laser in the airway, it is judicious not to tape the anaesthetic tube to patient's mouth to secure it.

9.2. In the event of an airway fire

- Disconnect the breathing anaesthetic circuit from the tracheal tube.
- Remove the burning material. It should be put out immediately by other members of the operating team.
- Re-establish the airway and ventilate with air until certain that all burning material has been removed, and then switch to 100% oxygen.
- Examine the airways to remove debris from the ignited material and assess the damage.
- Send the patient to ITU for further management.
- Retain all the material and report the incident to appropriate authority (and the Laser Protection Adviser) to investigate the event.

10. Summary (surgical fires)

All surgical fires are preventable and therefore, indefensible.

11. Laser plume

During routine laser surgery, a large amount of surgical plume is produced at the site of the operation, and spreads into the operating room. Standards now have eliminated the term smoke, and refer to all airborne contaminants resulting from vapourising tissue with energy based devices (lasers, diathermy, ultrasonic instruments, etc.) as surgical plume. Plume is a combination of smoke, cellular particulates, organic materials, inorganic materials, and gases (ISO TC121).

11.1. Contents of plume

The contents of plume are extremely variable and depend upon the type and density of the tissue. Broadly, the contents are divided into biological and chemical components. IEC 60825 describes the content of plume as: biological material consisting of viruses, cancer cells, blood fragments and bacterial spores. Chemical components are carbon monoxide, polyaromatic hydrocarbons, and various toxic gases. Plumes may also contain chemicals such as formaldehyde, hydrogen cyanide, acrolein, and benzene.

11.2. Production of plume

The ablative action of laser energy differs from conventional instrumentation in one important respect. Ablation is effected by thermal vaporisation, which results in the production of smoke and vapour. Within a short time of laser vaporisation, the whole theatre is filled with smoky air with an unpleasant odour, similar to burning flesh. Apart from this unpleasant odour, contamination of the operating environment by the products of tissue vaporisation is a major health concern for the theatre personnel.

11.3. The issue of pollution with laser plume

The issue of pollution needs to be addressed in a systematic manner, as follows:

- Is the operating environment being polluted?
- Is the operating team at risk from this pollution?
- What measures can be installed to eliminate or minimise this risk?

11.4. Pollution of the operating environment with plume

Much work has been undertaken to determine the components of surgical plume. Transmission risk from bacteria or virus-infected lesions was identified following the study of cultures grown from samples taken from smoke collected during vaporisation. Further samples were also collected from evacuators used during laser resurfacing. The following sections present the findings from several studies.

11.5. Literature review: Potential to hazard from inhalation of plume

Bigony (2007) carried out an extensive literature review on the risks associated with exposure to surgical plume.

Gatti *et al.* (1992) collected multiple air samples in the operating room during reduction mammaplasty carried out with electrocautery knife, and tested them for mutagenic potential in tester strains of *Salmonella typhimurium* (TA98 and TA100). They found smoke to be mutagenic to the TA98 strain and concluded that, while there was no convincing evidence of similar mutagenicity in operating personnel, limiting smoke exposure was advisable.

Wenig *et al.* (1993) exposed Sprague-Dawley rats to Nd:YAG laser exhaust passed through smoke evacuation filters. Histological analysis revealed alveolar congestion and emphysematous changes. Controls exhibited similar changes, but to a milder degree. They concluded laser plume results in pathological changes in rat lungs. Based on their findings they advocate use of effective smoke evacuation.

Fletcher *et al.* (1999) based their study on recurrence of malignancy at port site following laporoscopic surgery for malignant disease. They investigated such potential by cauterising pellets of B16-F0 mouse malignant cells and collecting the plume in culture medium. Their finding confirmed the release of viable malignant cells in the plume, explaining the recurrence at port site.

Garden *et al.* (2002) conclusively demonstrated plume transmission of bovine papillomavirus. They used CO_2 laser at various clinical settings on cutaneous lesions and re-inoculated the plume in to the skin of calves. Lesions, infected with the same virus type as in the plume, developed at every inoculated site. They state that to their knowledge this was the first conclusive demonstration ever of plume-based transmission of disease, and advocate strict care while treating viral lesions.

Moot *et al.* (2007) demonstrated the presence of volatile organic compounds in diathermy plume and obliquely suggested that since there is no evidence that such compound can be inhaled safely, it is necessary to avoid breathing them by the use of smoke evacuators.

Caloro and Brusis (2003) noted only one report in the literature on iatrogenic infection with the human papilloma virus (HPV), and added one further such case. A 28-year old gynaecological nurse who assisted regularly in electrosurgical and laser surgical excisions of ano-genital condylomatas developed recurrent and histologically proven laryngeal papillomatosis. The Virology institute confirmed a high probability of correlation and accepted laryngeal papilloma in the nurse as *occupational disease*. They state that although HPV-DNA material has been frequently detected in laser plume, there was no conclusive proof of their transmission, implantation and production of lesions in host recipient. They postulate that due to relatively enclosed operating site of these lesions in laryngeal papillomatosis, the probability of transmission is small. Such is not the case in condyloma excisions in gynaecological operation, due to direct escape of plume into the open and wider operating space, and also relatively larger size of the lesions.

11.6. Transmission risk from bacteria-infected lesions

The cultures from plumes were positive for *Corynebacterium*, *Neisseria* and coagulase-negative *Staphylococci* (Capizzi *et al.*, 1998). Samples of plumes generated from *Escherichia coli*-inoculated dental root canals by an argon laser proved positive (McKinley and Ludlow, 1994). However, cultures from bacterial growth were found to be inversely proportional to the extent of the laser exposure of porcine skin inoculated with a given quantity of bacteria. The more extensive the exposure of the skin, the less extensive was the growth of bacteria in the culture. The potential risk of bacterial diffusion in the atmosphere due to pollution by a smoke plume is thus negligible (Mullarky *et al.*, 1985).

11.7. Transmission risk from virus-infected lesions

Research into smoke plumes produced during laryngeal papilloma vaporisation failed to reveal HPV-DNA in the plume (Abramson *et al.*, 1990). Nevertheless, lasing appears to induce viral spread to the epithelium surrounding the operated site. Meticulous cleaning of the operating site and surrounding tissue with a wet swab is strongly recommended (Ferenczy *et al.*, 1990b).

- Isolation:

Studies have revealed proviral HIV DNA in debris taken from Silastic aspiration tubes following vaporisation of infected cultured tissue (Baggish *et al.*, 1991).

- Viability of the virus material:

Experimental research has shown that the oral poliovirus vaccine survives excimer laser ablation (Taravella *et al.*, 1999).

- Viral transmission:

Following vaporisation of human papilloma virus-infected tissue from the lower genital tract, enucleated keratinized squamous epithelial cells were recovered from the inner wall of a hollow cylinder, through which vaporisation was effected with a CO_2 laser (Wisniewski *et al.*, 1990).

- Clinical observation:

Despite the above findings, it has been demonstrated that a surgeon who removes warts from several anatomical sites is not at a higher risk of contacting a virus lesion than a general population (of surgeons). However, the human papillomavirus (HPV) strains that cause genital lesions show a marked predilection for the upper airway tract, and thus laser plumes containing these viruses could be hazardous (Gloster and Roenigk, 1995). Despite this predilection, no HPV was detected in the nasopharynx, eyebrows or ears of surgeons following laser-assisted surgery for genital papillomatosis (Ferenczy *et al.*, 1990a).

11.8. Transmission risk from malignant tissue

The issue of the risk of contamination and the transmission of malignant cells to the operating team has also been addressed (Health Devices, 1992). CO_2 laser vaporisation produces smoke condensates. Research based on the vaporisation of dog tongues has shown mutation of certain strains of *Salmonella typhimurium*, similar to the mutation following cigarette smoking. This work raises the possibility of potential mutagenicity following exposure to laser smoke (Tomita *et al.*, 1981). In addition, experimental investigations have demonstrated that smoke produced by either lasers or electrocoagulation irritates the airway and modifies alveolar gas exchange (Baggish and Elbakry, 1987; Freitag *et al.*, 1987; Wenig *et al.*, 1993). Surgical masks do not protect against particles smaller than 0.8 µm (Nezhat *et al.*, 1987). Even the so-called ‘laser masks’ do not filter 0.1-µm particles (Kneedler and Purcell, 1989).

11.9. Is inhalation of laser plume a health hazard?

11.9.1. Review of literature

Review of literature shows that the plume contains: Viable biological material, of a size as small as 0.1 microns, known to cause diseases, and chemical material known to be toxic to health.

11.9.2. Experimental evidence

Under experimental conditions the researchers were able to demonstrate transmission of pathological conditions to the host. They were also able to identify pathological changes in lung tissue.

11.9.3. Personal experience

One of the authors of this chapter (VO) started working with the CO_2 laser in 1982. Most of the work was in the oral cavity and in the larynx using a laryngoscope. There was no knowledge of hazard from plume inhalation. A full frontal exposure was the norm, and the only protection was removal of smoke with a suction cannula attached to the wall suction unit, and a loosely worn surgical mask. The odour was that of burning flesh and distinctively unpleasant to the extent that pipe smoking was given up.

Two years on, nasal obstruction ensued. Hopkins rod examination at a trade exhibition showed enlargement and crusting of the anterior end of middle turbinates. Partial turbinectomy successfully restored nasal breathing. Hand in hand, a dual suction unit was developed with filter capable of removing 0.1 um particulate size. One portal was connected with tubing to the suction cannula placed in the immediate vicinity of the operating site. The other portal was connected to a funnel, which was clipped to the head towel and positioned at the corner of the mouth. There was an immediate improvement in the odour of the air in the operating room, an indication enough of the effectiveness of the suction unit.

In order to label an entity as occupation health hazard, the following criteria must be filled:

- Exposure occurring during employment.
- Contraction of the disease during the course of employment.
- The condition must be causally related to the exposure.
- Prevalence of disease in exposed persons is greater than in the general population.
- The disease is experimentally reproducible.

The evidence presented above, certainly does not meet the criterion that plume inhalation leads to an identifiable reproducible disease. However, the work of certain researchers does suggest that the plume is not altogether innocuous and that removal of plume from the operating environment is a step in right direction. For clinical issues related to laser plume in recurrent respiratory papillomatosis, see Chapter 9.

11.10. Removal of smoke from the operating environment

The extensive literature review indicates that laser smoke has *undesirable* presence in the operating environment. In addition to safety aspects, smoke has an unpleasant, noxious odour, not unlike burning flesh. It also blocks a clear view of the operating site, since it is heavier than air, and stays at the point of generation.

Staff protection from surgical plume should be considered an integral part of laser and diathermy usage. The protection is achieved by wearing personal protective equipment (PPE), general ventilation of the theatre, hospital wall suction units and mobile dedicated suction evacuators.

11.11. Personal protection equipment (PPE)

In everyday surgical practice, this is no more than a surgical mask. Surgical masks during routine surgery are primarily used to protect the operation site from wearer's respiratory emissions. Some types of masks also provide protection to the wearer, from direct splashes or sprays of infectious blood and body fluids.

Surgical masks are made from flat, non-woven fine fibres. These act to trap particles by impaction, diffusion and interception. Impaction is simply due to inertia of large size particles (*i.e.*, they do not have inherent motion) and therefore, cannot continue their travel with the air flow. Interception is effected by mechanical obstruction of large size particles as they come in contact with the fibres. Diffusion is due to collision of small particles with air particles, thus deviation from the main air stream.

The masks are not fit-tested or checked as respiratory PPE, and are usually worn loosely. They do not provide an effective seal or filtration level against surgical plume, which contains aerosol contaminants. Tightly worn mask impair comfortable breathing on the part of the wearer. Mask materials filter properly, only when dry, and because they become damp from breathing, are not useful after more than twenty minutes.

Kunachak and Sobhon (1998) concluded that size of the smoke particles from CO_2 laser are within the alveolar hazard zone and conventional surgical masks are not an effective way to protect the wearer against contaminants from the plume.

11.12. Built-in local exhaust systems

Hospitals have wall suction systems. However, these are primarily designed to remove fluids. If used as the only system to remove small volumes of surgical plume, a dedicated 0.1 micron plume filter must be placed in-line between the wall outlet and the floor canister. The filters will be clogged up very quickly since laser usage generates large amount of particulate matter. It is therefore necessary, for most surgical procedures, to use a dedicated smoke evacuator system during every plume producing procedure, to ensure maximum and rapid removal, and capture of contaminants.

11.13. Smoke evacuation systems

Smoke evacuators are either fixed central systems, or portable, mobile units. They consist of vacuum pump, charcoal to adsorb gases, ULPA filters with 0.1 micron at 99.999% efficiency rating for viral capture, a hose with an inlet nozzle, and a capture device. Since smoke is heavy, it lingers at the site where it is generated. The nozzle or the suction tube needs to be held close, and no further than 2 cm to the operating site where the smoke is generated. Most laser instruments have built in suction channels which extend right up to the 'business end' of the instruments (Fig. 3). In addition to providing safe and clean environment, their use results in clear visibility of the target and the surrounding tissue.

Fixed evacuation systems are incorporated into

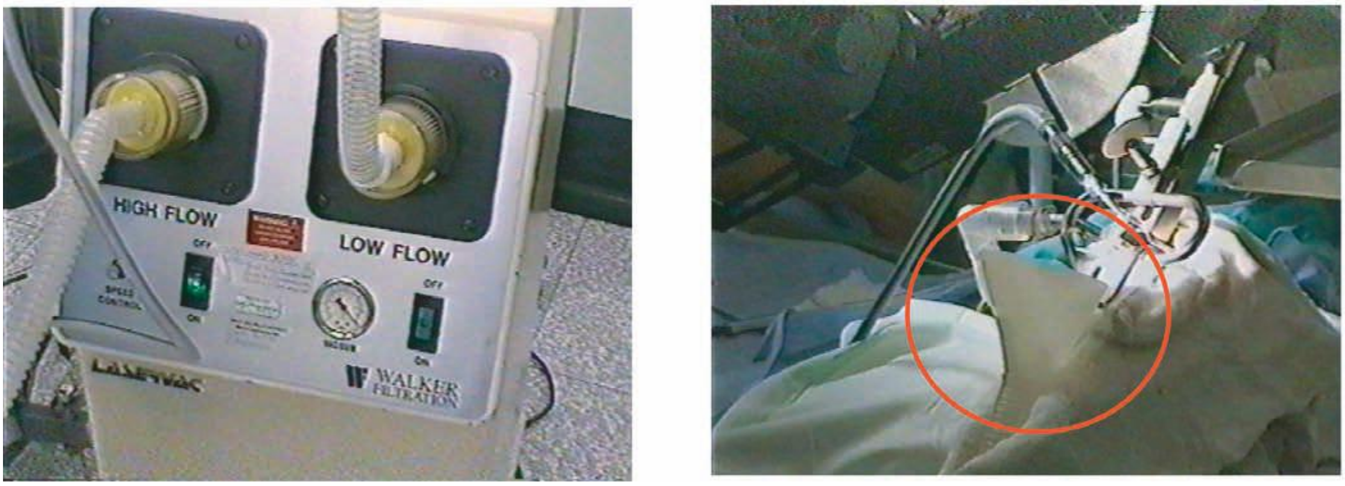

Fig. 3 Dual suction unit: high flow is connected to the suction cannula held in the vicinity of the operation field whereas low flow outlet is connected to the funnel held with S-hook attached to the laryngoscope.

surgical rooms or medical gas columns, requiring only a filter and delivery tubing to be installed for each case, and providing central capture and processing of airborne contaminants from all theatres in an operating suite. This can reduce the noise factor, and the amount of equipment needing floor space.

In order to reduce the overall concentration of pollution in the theatre, the authors strongly advocate the use of effective aspiration at the site of smoke production (Health Devices, 1992). This is easy to accomplish by using suction-based instruments, which are now universally available. The proximal end of the cannula is connected to the dedicated suction machine with a filter capable of eliminating 99% of 0.1 μm sized particulate matter (Ossoff and Karlan, 1984; Baggish *et al.*, 1988). Alternatively, a hand-held aspiration tube is placed near the operation site (Smith *et al.*, 1989; 1990).

Filters require regular replacement, in accordance with the manufacturer's recommendations. Filters that are designed to filter gaseous material will not cope with blood or secretions. A separate sump is introduced in order to collect liquid waste from the operation site. Even these measures may still leave some smoke behind, which will escape from the proximal end of the laryngoscope.

There is a wide variety of plume evacuations systems available, and selection should be based on an assessment including application and instrumentation to be used, type of capture devices needed, noise factor, portability, filter life and monitoring system, ease of positioning in theatre, ease of use, and maintenance requirements. While elimination of 100% of 0.1-μm particulate matter is not possible, it is aimed to remove at least 99% of the pollution, and thus greatly reduce the potential risks. In addition to aspiration at the operation site, the operating theatre should be ventilated and filtered (Dikes, 1999). If the patient is being operated on under local anaesthesia, the surgeon must synchronise the laser strikes with the expiration in order to avoid smoke inhalation. Thus, vaporisation occurs during the expiratory phase of respiration, which further reduces smoke pollution.

12. Summary (laser plume)

Symptoms resulting from laser plume exposure range from minor degrees of eye, nose, and throat irritation, nausea due to obnoxious smell and nasal congestion and fatigue, to more severe conditions such as triggering asthma and allergic reaction, and bronchospasm. These symptoms relate to the rise in both methhemoglobin and carboxyhemoglobin as plume is absorbed into the bloodstream, causing decreasing oxygenation to tissues, as is known in the process of smoke inhalation (Ott, 1994; 1997).

Nevertheless, these are short term health effects usually lasting 24 to 48 hours. However, permanent disability can be the result – *e.g.*, hypersensitisation. Due to the weight of evidence in both literature, and international standards, plume evacuation should be considered an occupational safety hazard and not merely a preference. In some places, compliance is mandatory, and as research continues to identify risks and hazards, greater emphasis on compliance is emerging.

The current state of regulation, standards, professional recommended practices, and local rules, are good supportive evidence to continue to take precautions outlined above.

13. Electrical hazards

No electrical hazard should ever become a reality if all the work related to installation and maintenance of lasers is carried out by no other than a qualified electrical engineer as per the manufacturer's instruction manual. It is recommended that standards for inspection and set-up of electrical equipment be followed by staff prior to laser use, including a visual check of the cord connecting the footswitch, which can be easily damaged during handling.

14. Noise pollution

Modern theatres generate considerable noise. Suction tubes operate intermittently to remove plume, and laser machines can be noisy during long operations. There is a potential of causing miscommunication between the operating staff and theatre staff. The laser console should always be visible to the surgeon so that he or she can confirm that the settings are accurate as required. Good verbal communication between laser user and laser operator is essential, so that the laser can be put in stand-by, or ready at appropriate times during the procedure.

15. Alignment

All lasers operating in the infra red region require guiding beam to identify their path. In CO_2 and Er:YAG lasers, delivered by rigid, reflecting attachments, the aiming beam is usually provided by additional low-power visible red diode laser. The two lasers must be accurately superimposed and should remain so at all times to ensure target hits. Misaligned lasers are a danger to the patient and the operating staff. Alignment should be checked by test firing on a wet wooden spatula placed on damp towel, prior to each laser session, whenever the laser is moved from one room to another, and whenever the delivery system is changed (ex: handpiece to microscope). In critical areas such as stapes surgery, some surgeons test the alignment just prior to the stapedotomy. The test firing is carried out by placing the spatula as near the target zone as possible, just outside the ear, on the side of the face, although this is now considered unsafe practice – and unnecessary due to the improved stability of the optical train. Nevertheless, in addition to alignment, this pre-procedure test is also used to verify that the beam mode is accurate, so the surgeon can be assured of consistent tissue effects. If delivered by fibre, this test is not performed, however, the fibre is examined and calibrated prior to use.

16. Calibration

The digital display on the console is not always the accurate measure of the laser performance. Regular in-house calibration can be undertaken by test firing on a block of Perspex and comparing the burn with the previous ones. A log of the result will show if the performance has deteriorated through the passage of time. A performance within 80% of the manufacturer's data is an acceptable lower limit.

17. Access to laser suite (NHZ: Nominal Hazard Zone in USA and Canada, NOHA: NO Hazard Area, International standards)

The Nominal Hazard Zone (NOHA is the term used in ANSI standards) or Nominal Ocular Hazard Area (NOHA is the term used in IEC standards) describes the space in which the level of direct, reflected or scattered laser energy can exceed the Maximum Permissible Exposure (MPE is a calculation that determines the level of laser light the unprotected eye can tolerate before injury occurs.

In practice, it is not necessary to do this calculation, and generally accepted practice is to designate the entire room in which a laser is used as the laser controlled room. Access to the laser controlled room should be restricted to only properly trained and essential personnel. Any spectators must follow all safety instructions, including adhering to the use of protective eyewear.

18. Laser signs

The purpose of laser signs is to alert personnel that they are entering a laser area with potential dangers. Signs must be posted on every door entering the NOHA, and be placed visibly, at eye level, and they must be removed or covered when laser use is finished. The laser sign should include international laser symbol, type of laser being used, classification, visible and/or infrared, and its maximum output. Wavelength-specific eyewear should be available at the entrance of the laser-designated area with a warning that protective eyewear must be worn prior to entering the room.

19. Laser nurse or laser technician

A designated and trained person should take charge of the laser equipment and remain in charge throughout the laser session. He/she must:

- Secure the key for the console panel.
- Return it for safe keeping.
- Know the control panel and emergency cut off procedure.
- Know the location and operation of the fire extinguisher.
- Maintain the log book and be responsible for incident reporting.
- Communicate with the laser user at all times. (standards designate *user* as the person delivering the energy and *operator* as the person at the controls).
- Monitor the entire room for safe practice during laser use.

20. Pregnancy and laser environment

Lasers are in the non-ionising portion of the EM spectrum, they cannot cause cellular damage, mutagenic or carcinogenic effects, and are therefore safe for use on pregnant patients, or in the presence of pregnant staff. It follows that there is no reason to ban pregnant staff from working with lasers.

If a laser beam accidentally strikes someone, most of the beam absorption takes place at the surface of the skin. If the beam is sufficiently intense and the person does not move out of the beam, then it will burn its way deeper into the dermis and sub-dermis. Absorption, and therefore damage, is always greater at the skin surface than below the skin. So there is no evidence that a laser can cause damage to a developing foetus without first burning through the skin of the mother.

21. Adverse incident management

The Healthbeatblog site reports six surgical fires in a twelve-month period at the well-respected Cleveland Clinic (Maggie Mahar, www.healthbeatblog.org) in the US. All fires were due to ignition of flammable skin prep material when ESU was used. However, these fires were not reported, since no identifiable channel existed. Thus, although a distinct repetitive pattern of accidents existed, the alcohol-based prep was not withdrawn to prevent further potential fires. It is conceivable that if a channel for reporting had existed, the hazard would have been noted and steps taken to prevent further fires.

True rates of surgical adverse events may not be known since reporting varies from state to state and country to country. Unless there is morbidity, reporting is generally not mandatory. Furthermore, patients involved in litigation or receiving compensation, are asked to sign a confidentiality agreement, and risk managers contain such reports internally. In the UK, Adverse Incident Management Operational Guidance is mandatory within NHS hospitals. NHS Direct NP008 sets out detail guidance for responsibility for reporting, investigation, management and prevention strategy. The aim of the management process is not so much as to apportion blame as to contribute to the National Reporting and Learning System being developed by the National Patients Safety Authority. The hospital reporting system enables management to comply with the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR 1995). The main purpose of these Regulations is to provide information to the Health and Safety Executive to assist with accident prevention. Under the Regulations a report must be submitted within ten days. If a person is unable to work for more than three days because of an injury resulting from an incident at work, this must be reported under the Regulations Indemnity

This topic is beyond the scope of the work presented here. Its inclusion is merely to reinforce the readership about an additional hazard the laser may bring, and thus even greater importance of indemnity cover.

Equipment malfunction, provided the device is used as per manufacturer's instructions, will normally be covered by the manufacturer's indemnity. Fibres marketed for single use should be used as such. Laser safe anaesthetic tubes are also marketed for single use. Any multiple use (mostly based on cost considerations) will nullify indemnity, unless the manufacturer provides written protocols for cleaning and sterilising the product, and the user documents compliance with those protocols.

22. Laser training

Laser surgery is unique in skill demands. Laser technology requires understanding of a number of aspects which include:

- Basic physics and laser tissue interaction.

In ENT, it is not uncommon to use two or three different types of lasers: *e.g.* CO_2, KTP, Diode, Ho:YAG, Pulsed dye, etc. Each laser has its own specific performance criteria which optimise surgical outcome.

- Familiarity with console and delivery systems.

It is the user's responsibility to ask the control panel operator (this can be a nurse, a technician, a biomed, etc.) to set the required beam parameters such as power, exposure time, single shot or continuous wave and so on. The clinician thus must be familiar with the console so that he or she can personally confirm the setting. Parameters are surgical dose, and only the clinician can prescribe the dose to be used.

- Potential hazards and risks.

Although safe use of lasers involves team effort, ultimately, it is the surgeon who pulls the trigger when he / she activates the beam and carries the major part of the burden in the event of an incidence or accident. Notwithstanding, each member of the team is expected to do their bit to avoid hazard by reason of their training and will have to share the responsibility.

23. Standards, regulations, and practice guidelines

23.1. Standards

Standards are not regulatory, but are consensus documents for best practice. As such, they are often considered as the usual and customary practice in a given area, and may be considered as the basis for medical-legal citations in cases of patient or staff injury, accident, or untoward occurrence. They should thus serve as strong motivation for laser users to gain knowledge of the established rules for safety, and mandate compliance with them.

Most laser standards use mathematical approach to formulate theoretical basis for safety. They will provide the laser user a working knowledge of the technical material, exposure limits, nominal ocular hazard area, optical density levels, maximum permissible exposure, classifications, etc. Should *technical* assessments become necessary, as in cases of accident investigation, or establishment of a research project, clinicians can muster the services of medical physicist, a laser protection advisor (LPA), or a laser safety officer (LSO).

23.1.1. International Electrotechnical Commission (IEC)

International Electrotechnical Commission (IEC) documents 60601 and 60825 are the global benchmarks for laser safety, and include guidance for manufacturers, professional clinicians, and administrators of laser facilities. They are used as the foundation for most countries' national standards. In some countries (USA, Australia, Canada), these standards are harmonized with the national standards.

23.1.2. Australia

In Australia, national standards AS 2211and the AS 4173, are used in conjunction with the IEC 60825 and the 60825 TR8. These standards are the basis for state regulations, such as those adopted in Tasmania, Western Australia, and in Queensland under the Radiation Safety Act 1999. National criteria for laser licensure and registration will soon be adopted.

23.1.3. USA

In the United States, a number of states have regulations requiring registration of laser systems, and proof of administrative controls as defined in the American National Standard Institute documents (ANSI Z136.1, ANSI Z136.3). ANSI standards are mandated to harmonise with the IEC 60610222-- and the IEC 60825, and are the basis for laser safety requirements as determined by the Occupational Safety and Health Administration (OSHA, which is a governmental branch of the Department of Labor and carries the authority to issue citations and/or legal action, for non-compliance). Professional organisations, such as the American Society for Lasers in Medicine and Surgery, International Federation of Perioperative Nurses, American Society of Anesthesiologists, College of Surgeons, etc. have produced a variety of position statements, standards, and Guidelines for laser safety, airway management during Head and Neck surgery, office-based laser procedures,perioperative procedures for safe patient care in laser procedures, and credentialing criteria for both physicians and non-physicians providing laser treatments.

23.1.4. Europe

In Europe, the IEC-60825:1994 document offers non-regulatory guidance for identification and control of major hazards associated with medical lasers. The companion document 60825-Part 8, contains more informative sections with expanded descriptive procedures focused on laser users, and is a helpful outline for policy development, and safety management.

In the UK, the Department of Health has published Guidance on the safe use of lasers, intense light source systems and LEDs in medical, surgical, dental and aesthetic practices. This defines the role and responsibility of the Laser Protection Adviser (LPA). The LPA must be knowledgeable in the evaluation of laser hazards and has responsibility for advising on their control. In the NHS, and in independent hospitals, there is a requirement to appoint an LPA where lasers are used. The LPA will assist in undertaking risk assessments and ensuring that suitable Local Rules are in place.

Guidelines are usually drafted by professional organisations. There are also commercial organisations, which would, for a fee, inspect the private facility and recommend any shortcomings to meet the required standards and rules.

23.2. Motivation to use standards

23.2.1. Medical defense organizations

In the UK, medical defence organisations do not stipulate skill acquisition as a pre-requisite to defend alleged negligence due to laser usage. They simply take a view that it is easier to defend a surgeon in case of a mishap, if he/she has undergone recognised training and holds a certificate to that effect.

23.2.2. Academic bodies

Likewise, academic bodies are content to award a medical or surgical qualification and leave it up to an individual to practice according to his or her own-assessed competency.

23.2.3. Employer liability

In national healthcare systems, such as the National Health Service (NHS) the employing authorities have a *common law duty* to ensure that the employees have adequate skill to undertake their work. They also have a duty under the Health and Safety at Work legislation to protect staff and members of the public from injury or ill health arising out of any activity undertaken by or on behalf of the employer. This clearly applies to inappropriate or incorrect use of laser by other members of the staff. Furthermore, under the same legislation they have an additional duty to ensure that equipment is adequately maintained. In the final analysis, the onus must be on the individuals to attend suitable courses to protect their patients, staff and themselves.

23.2.4. The professional bodies

The professional bodies such as the British Medical Laser Association award annual recognition to the laser courses for their educational contents. The Royal colleges require their members to undergo fifty hours of continuing medical education (CME) each year, but do not specify laser training as part of the CME.

23.2.5. Manufacturers and vendors

There is no standard, regulation, or requirement anywhere in the world that requires a formal training in laser technology as a pre-condition for sale. The extent of commercial involvement allowable in laser (and in all medical) education, varies from country to country, and the quality and content of such courses must be evaluated by the prospective student.

23.2.6. General Medical Council (GMC)

In the UK, in the event that there is a mishap, it is likely that the General Medical Council (GMC) would take a disciplinary action against any laser user who is unable to show that he/she has received an adequate training in the laser usage, should a mishap occur. One of the authors (HM) has acted as an expert witness for the GMC in which severe disciplinary action was taken against an individual who used a laser inappropriately.

24. Audit

Audit is the routine and periodic examination of all aspects of a laser programme, providing the information needed for quality assurance and management in healthcare facilities. It is performed by the LSO or appropriate compliance officer, and includes interviewing staff to assess levels of knowledge and learning needs, inspection of all equipment and facilities, review of documentation, and observation of procedures to assess compliance with policies and procedures. Results are documented and reported to the laser committee or appropriate administrator and then once the recommendations are completed, on-going monitoring will determine whether or not the standards are being followed. Audit should be performed once a year, or if there is a great deal of laser usage, and the LSO may determine that it should be done more frequently.

25. Conclusion

Laser accidents continue to surface. A zero score perhaps is unachievable. Laser risk management is key to identifying the risks and taking steps to ensure the safety of the laser procedure as far as is reasonably practicable. It is a simple process based on knowledge of laser tissue interactions, delivery systems, and applicable standards, and has four phases:

- Identification of hazards;
- Identifying risk of exposure to the hazards (who may be harmed and how harm can happen);
- Once risk is identified, control measures are developed to mitigate those risks, audit, document findings and follow up to ensure that all areas of risk have been addressed.

The laser produces an intense beam which can cause significant damage to eyes and other body tissue. Lasers operate in an oxygen enriched environment in the theatre, which will support combustion of flammable material. Laser plume is an unwanted by-product of laser tissue interaction. It must be treated as waste and removed efficiently to maintain a pollution-free environment for the staff. Training in laser technology is essential for the whole team and not just for the operator.

The incidents can be kept to a minimum by the following ‘common-sense’ measures:

- Identify the risk;
- Once identified, what can be done to avoid or minimise the risk?

In most cases, it is possible to minimise the risk by requiring everyone to follow a routine procedure checklist and insisting on compliance each time the laser is used. As an example, safety eyewear must be worn by everyone who enters the laser zone. Someone who is simply walking in and out the zone may consider the risk minimum and it probably is. But by insisting on compliance, no matter how insignificant it is, you can develop a culture of safety.

- Cost economics at the administration level can lead to cuts on training resources, attendance at courses and such.
- Learn and teach others through maintenance of log or event book which serves to improve risk management through experience.
- Create an atmosphere of awareness by periodic inspection, maintenance of equipment and training.
- Understand the meaning of such phrases as complications (mostly avoidable), hazards (mostly anticipated) and accidents (mostly rare events if first two are adequately catered for).
- Undertake self-audit. This aspect of risk management goes a long way to optimizing surgical or medical outcome.
- Be aware of regulatory, non-regulatory, advisory documents, protocols, guidelines etc. Most countries have a plethora of these documents, and their compliance will go a long way to defend an untoward event.

The most serious and non-defensible risk is an untrained user.

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MCQ – 3. Risk management in laser technology: Primum non nocere – First do no harm

1. Laser hazard arises from
   a. Intense beam
   b. Laser plume
   c. Flammable operating environment
   d. Untrained laser operator
   e. All of the above

2. In case of ignition and fire of the anaesthetic tube the immediate action is to
   a. Douse the fire with water
   b. Shut off all gases
   c. Switch the laser machine off with an emergency stop
   d. Pull the tube out of the patient's throat

3. Of all the lasers in ENT practice, CO_2 laser is most hazardous because
   a. It is the most commonly used laser in the airway
   b. It is delivered to the target as free beam
   c. Its beam has caused more airway fires than any other laser
   d. CO_2 wavelength is maximally absorbed by water containing mucosa
   e. All of the above

4. Eye is best protected from the strike of the CO_2 laser beam by
   a. Aversion response
   b. Prescription glasses
   c. Regular general purpose protective goggles
   d. Dedicated laser safety eyewear
   e. Using fibre optic delivery of laser beam to the target

5. Anaesthetic tube ignition risk can be minimised by
   a. Reducing oxygen concentration to a minimal percentage
   b. Using tubeless anaesthetic techniques
   c. By foil-wrapping flammable tube
   d. By protecting cuff with wet gauze
   e. By using laser safe tube
   f. All of the above

6. In case of a laser accident, the *primary* responsibility lies on
   a. The physician using the laser ('laser user')
   b. On the laser technician ('laser operator')
   c. On the anaesthetist ('member of the team')
   d. On the theatre staff ('laser worker')
   e. On the hospital management ('the employer')

7. The issue of laser safety is the responsibility of
   a. The administration of the establishment where the laser is used
   b. The ' Laser Team'
   c. A Government body such as 'The health and safety at work' department
   d. The patient
   e. Varies from country to country and from state to state within some countries

Chapter 4

Equipment and instrumentation

V. Oswal and M. Remacle

1. Introduction

Surgery with laser technology entails the use of complex equipment, consisting of the laser machine, delivery system for the laser beam with optical fibre or micromanipulator attached to the operating microscope, and dedicated smoke evacuator. It is also necessary to modify the anaesthetic technique, and to use suction-based instruments. Finally, imaging and monitoring equipment is desirable so that the nursing and the anaesthetic staff can follow the progress of surgery and anticipate the ongoing requirements of the operating team. A well-organised protocol for the placement of these items, and well-orchestrated laser discipline, will go a long way in creating a sound working environment and safety for the patient.

2. Laser set-up

Laser surgery requires a specific configuration of the theatre lay-out so that the operative procedure can be undertaken efficiently and safely (Fig. 1). Close consultation with all members of the team helps in the understanding of each other's requirements, which, at times, may be conflicting.

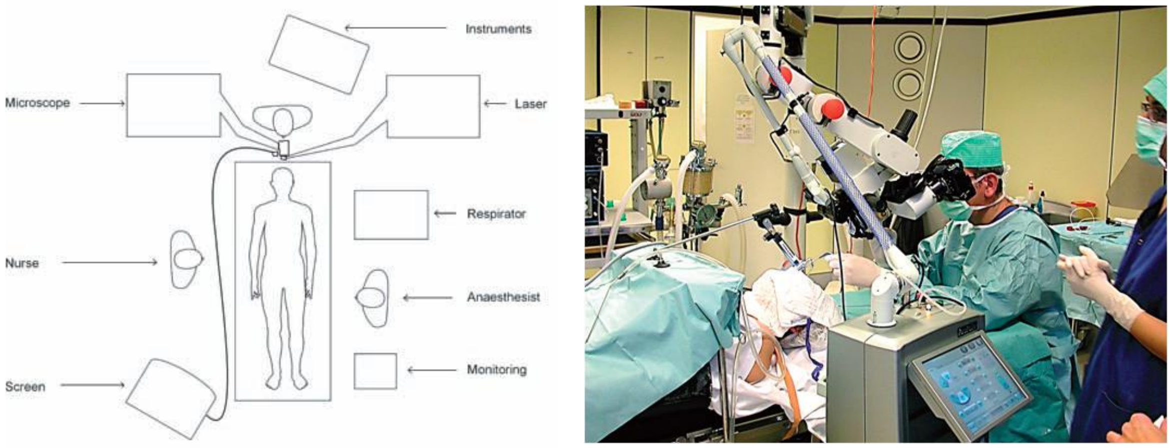

Fig. 1. Typical configuration of the theatre lay-out for laser surgical procedure.

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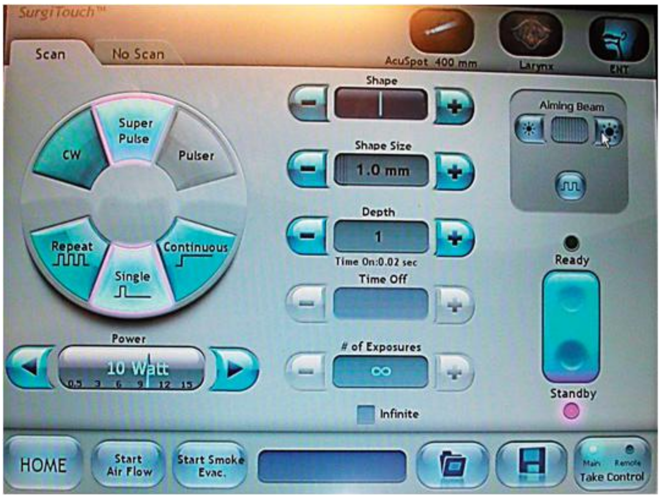

Shape Size 1.0 mm
Depth 1
Time On:0.02 sec
Power 10 Watt
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Fig. 2. CO_2 laser panel

In the following paragraphs, the laser set-up will be considered under the following headings:

- the laser
- laser delivery systems
- smoke evacuation system
- dedicated eyewear
- dedicated anaesthetic technique
- video monitoring and archiving equipment
- dedicated laser instruments
- advanced laser accessories
- instrumentation for various laser procedures

3. The laser

The CO_2 laser (Fig. 2) was introduced into ENT surgery in the 1970s, and by the 1980s, it had become the laser of choice throughout the world. Its unique property of shallow thermal damage makes it an ideal laser for laryngeal surgery. The CO_2 laser beam is collimated, and thus retains its power over a long distance, in the free-beam mode. Anaesthetic tube protection from inadvertent direct or indirect laser strikes is mandatory. The beam cannot be transmitted via common silica fibres, and is mostly used as a free beam. During laryngeal surgery, the teeth and lips are susceptible to unintentional strikes and burns.

Although the CO_2 remained the first choice laser, it did not meet the needs for ablation of all heterogenous tissue and anatomical locations in ENT surgery. Its poor haemostatic properties and non-transmission via optical fibres makes it unsuitable for a variety of nasal procedures. A second laser was inevitable, and several competitors have made in-roads in recent years. The Ho:YAG, KTP, and diode lasers (Fig. 3) are the major contenders for this second place. Among other considerations, the choice depends on the capital available and the revenue costs. The ultimate purchase is also governed by the aggressive marketing and the extent of the support facilities offered by the industry. The following paragraphs cover laser technology in general, with specific mention of a particular laser where applicable.

3.1. Optimal laser performance

The control panel of the laser machine consists of user-controlled settings for power output and exposure times. The power output denotes the optimal performance of the machine. However, over the passage of time, the quality of the cylinder and the optical cavity deteriorate. The reading shown on the output meter no longer corresponds to the actual power delivered in the beam. Used daily, the life span of an operating theatre CO_2 laser ranges from five to ten years. Moreover, there are inherent losses in the delivery system, particularly when waveguides are used. Debris sticking to the tip of the optical lens will alter the effective beam output at the target.

Thus, the beam power depends on laser type, manufacturer's specifications, and spot size, performance of the delivery system, etc. For consistent results, it is necessary to introduce some method of regular pre-session calibration, and if necessary, the power output should be adjusted upwards, in order to account for the under-performance, whatever the cause.

It is technically possible to measure the actual power output and to compare it with the theoretical power. The measured values encompass not only the power, but also the power density within the focal spot. Thus, the adjustment required to achieve the desired power (BS 4803 and ANSI-Z136.1) can be calculated. This correction is crucial for surgery in which a high degree of precision is required, *e.g.*, surgery of the otoslerotic footplate, or dissection of a sulcus vergeture.

4. Laser delivery systems

There are a number of laser delivery systems. It is necessary to appreciate that the peak effect of the laser energy is ultimately dependent upon

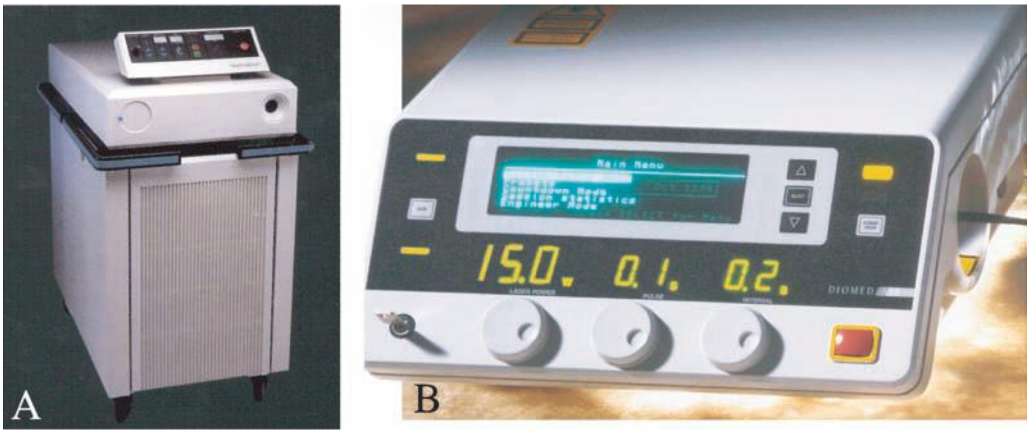


Fig. 3. Some other lasers marketed for ENT. A. Ho:YAG laser (Coherent two point one®). B. Diode laser (Diomed™).

the condition of the delivery system, which must constantly be kept in peak condition.

4.1. Inspection of optical delivery system

Optical fibres range from 200-1000 µm and can be used with a number of wavelengths: Ho:YAG, Er:YAG, diode, etc. Most fibres are made from silicate (Merberg, 1993). The under-performance of lasers may result from a loss of power due to degradation or poor maintenance of the optical fibres. In the case of re-usable fibres, the whole length of fibre should be inspected for its integrity. Any crack in the core of the fibre, not visible to the naked eye, will be indicated by reduced output at the tip. Uneven cleaving will distort the spot, with loss of power density, and therefore the fibre should be re-cleaved. If correctly cleaved, the emerging HeNe beam will be circular and intense. This will ensure that the invisible YAG beam will also have adequate power density.

During surgery, any sharp bend in the optical fibre should be avoided. Although the fibre may have been well cleaved, its tip can be damaged while being inserted into the narrow fibre channel of the endoscope or suction cannula. Tissue debris may stick to the tip, which will then start to heat up and char. A charred tip will heat the tissue excessively, and the laser parameters will change.

4.2. Rigid and flexible hollow waveguides

Rigid and flexible hollow waveguides are used to transmit the CO_2 laser beam since the CO_2 laser beam is not transmissible via the optical fibre. However, there is loss of power, and the emerging beam lacks sharp focus. The waveguide transmission cannot produce a spot smaller than 300µ in diameter (Slatkine, 1998).

4.2.1 FiberLase CO_2 fibre

In September 2010, Lumenis Ltd introduced the new two meters long FiberLase CO_2 fibre, powered by the AcuPulse 40WG CO_2 Laser, for multi-application use. The AcuPulse 40WG CO_2 laser offer 40 Watts of fibre input power. It has a He-Ne aiming beam delivered to the tip of the FiberLase fibre allowing accurate targeting of the tissue being treated. The manufacturers also state that the FiberLase fibre has the lowest beam divergence of comparable devices.

For clinical experience of this new CO_2 fibre, please see Chapter 59.

4.3. Precise transmission via the articulated arm

The visible red-emitting HeNe beam is superimposed onto the invisible CO_2 beam and they are transmitted as one beam in the articulated arm, which is a high-quality precision instrument that contains mirrors for beam transmission. Even the slightest displacement of the mirrors in the articulated arm will result in the loss of accurate superimposition of the visible aiming HeNe spot on the invisible active CO_2 laser spot. The active CO_2 laser beam will then fail to strike the target at the spot indicated by the HeNe beam (Davis and Simpson, 1983). Even a slight loss of superimposition may prove critical in precision surgery such as stapes footplate surgery. The laser should never be moved by holding the articulated arm. A damaged arm is much more expensive to replace than an optical fibre. In order to keep the laser and the optical delivery system in peak condition, the authors advocate routine biannual inspection by a qualified engineer.

4.4. Dedicated optical fibres

The laser beam of most YAG lasers can be guided to the operating site via optical fibres (Fig. 4). The beam emerging from the distal end no longer remains collimated. The angle of divergence varies with different wavelengths, but can average from 10-45°. While the coagulation effect is achieved with a low intensity, long duration laser pulse (*e.g.*, 10 W x 10 seconds), the ablation crater effect is obtained with a high intensity, short duration laser pulse (*e.g.*, 25 W x 4 seconds) (Fig. 5).

Contact fibres are used for laser interstitial thermotherapy (LITT) (Jager *et al.*, 1996). The fibre shape influences laser diffusion within the tissues (Bernstein *et al.*, 1995), and the wavelength type influences fibre wear (Wyman *et al.*, 1997).

A device that controls the heat at the tip of the fibre, the Fibertom®, is available commercially. The tissue in contact with the bare fibre reaches a temperature of several thousand degrees Celsius. The temperature at the fibre tip is different from the environmental thermal conduction. A white light indicates strong absorption. In the case of the Fibertom®, the white light serves as a warning signal for power adjustment and for verifying the cutting depth at the fibre tip. Thus, the Fibertom® provides increased safety. As the fibre loses contact with the tissue, the laser power instantly decreases automatically. This ensures minimal fibre wear. Power adjustment is also achieved via the cutting speed and thermal conductivity of the sectioned tissue. The depth of necrosis can thus be controlled (Romary, 1993; Slatkine, 1998). The hemispheric fibres concentrate the energy further away from the tip, and are mainly used for coagulation of the tissue.

4.5. Re-usable optical fibres and cleaving tools

Theoretically, the contact and non-contact fibres are disposable. The optical fibre for Ho:YAG laser is marketed for multiple use, while at the time of writing, the fibre for the KTP/532 is marketed for single use only. Buyers should check on this personally at the time of obtaining a particular laser. Single-use specifications substantially increases the cost of laser surgery. It is possible to sterilise and cleave the single-use specification fibre for re-use. A technician or nurse is usually responsible for this simple fibre maintenance. However, it should be appreciated that, if a fibre marketed for single use is cleaved, sterilised and re-used, the warranty is nullified and the onus lies on the user for any malfunction or infection. Express permission for re-use should be sought from the clinical risk manager after discussing the nature of the operation, method of sterilisation, etc.

The tip of the fibre can be kept free of debris by means of an air flux synchronised with the lasing. The transmittance of fibres used for rhinology applications ranges between 80 and 90%, due to inherent loss during transmission. For longer endoscopic waveguides for the CO_2 laser, transmittance is 60%. Therefore, it is advisable to use the CO_2 laser in the superpulse mode in order to attain higher power.

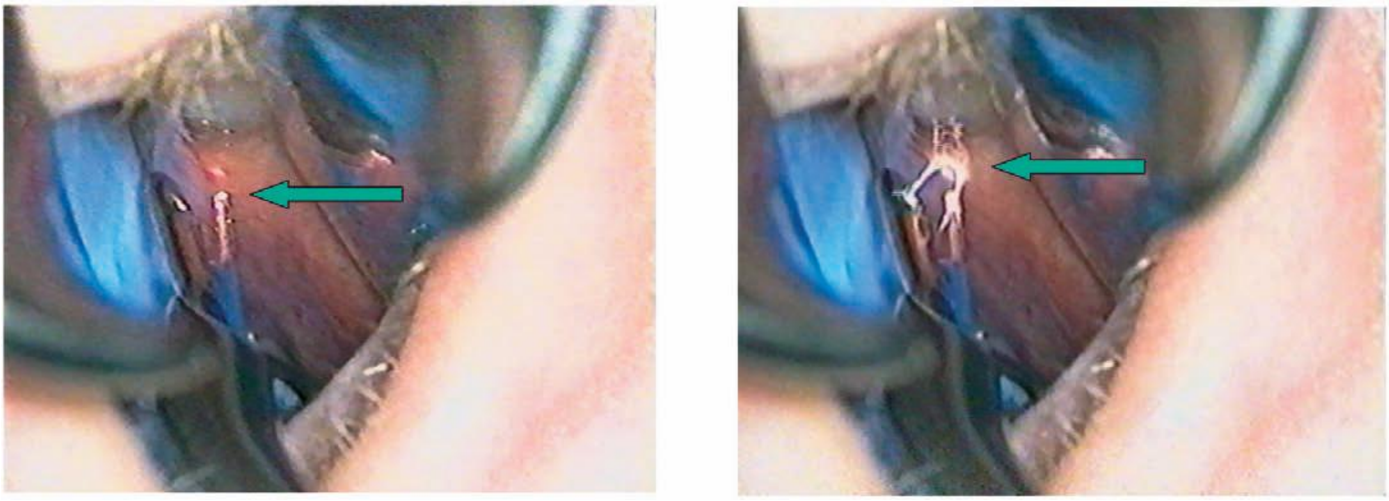


Fig. 4. Ho:YAG laser energy delivered via 365-µm optical fibre to inferior turbinate. Tissue debris splatters due to pulsed energy of this wavelength.

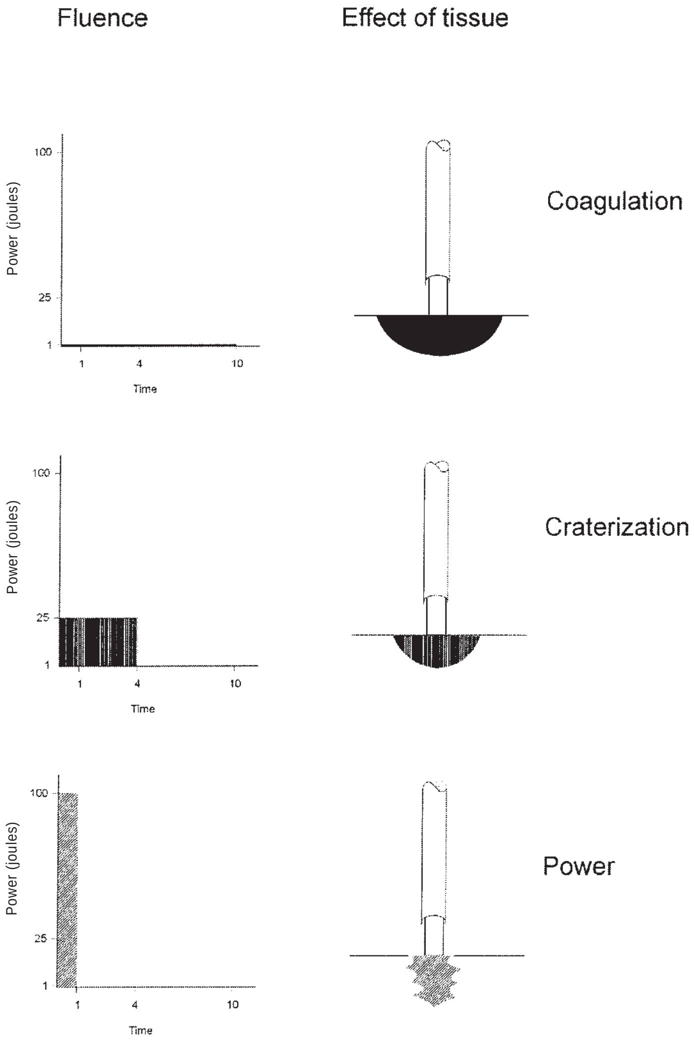


Fig. 5. Effect on tissue with changes in power setting and exposure time. A low-power and long duration results in coagulation whereas high power and short duration results in crater formation and vaporisation.

5. Smoke evacuation system

The ablative action of laser energy differs from conventional instrumentation in one important respect. Ablation is effected by thermal vaporisation, which results in the production of smoke and vapour. Within a short time of laser vaporisation, the whole theatre is filled with smoky air with an unpleasant odour, similar to burning flesh. Apart from this unpleasant odour, contamination of the operating environment by the products of tissue vaporisation is a major health concern for the theatre personnel.

The issue of pollution needs to be addressed in a systematic manner, as follows:

- is the operating environment being polluted?
- is the operating team at risk from this pollution?
- what measures can be installed to eliminate or minimise this risk?

The health hazard from smoke pollution has been recognised in the UK with the introduction of legislation on the Control of Substances Hazardous to Health (COSHH). There are specific and common law requirements that the operating environment should be free of products that are injurious to the health of workers, and that, by law, the onus for ensuring the compliance of these requirements lies with the employer.

In order to reduce the overall concentration of pollution in the theatre, the authors strongly advocate the use of effective aspiration at the site of smoke production (Health Devices, 1992). For fuller discussion on various aspects of plume, see Chapter 3.

6. Dedicated eyewear

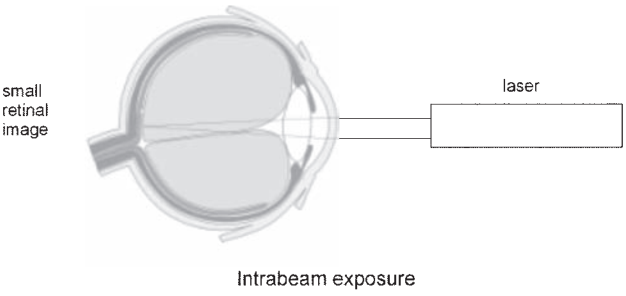
After anaesthetic tube ignition, ocular hazard is probably the second worse aspect of laser technology. The effect of the laser beam on the eye depends on several factors, as follows:

6.1. Wavelength

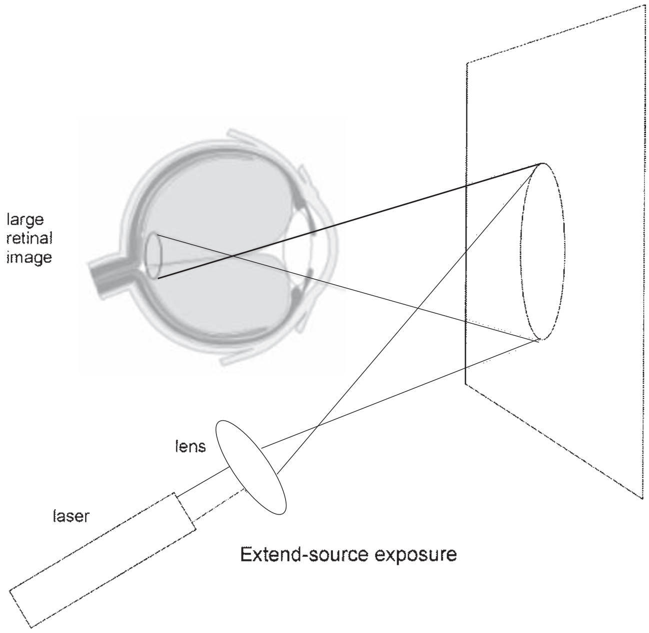
Tissues of the globe absorb the far-infrared CO_2 laser totally to a depth of approximately 100 µm. At worst, transitory exposure results in corneal burn. If the injury remains superficial, as soon as the corneal cells regenerate, within a day or two, the opaque whitish scar will disappear. The nearinfrared YAG beam and visible beams, such as the argon and KTP, are transmitted through the eye to the retina where, if irradiance is powerful enough, permanent damage will result in a scotoma.

6.2. Direct or indirect exposure

Exposure to the laser beam can occur either directly or indirectly. When the beam strikes the tissue directly, it is said to have suffered intrabeam exposure. Indirect exposure is due to the beam being reflected from the surface of the instruments. It is diffuse and thus, less dangerous (Figs. 6A and B).



A. The small spot size on the retina has an enormous concentration of damaging power due to converging effect of the lens of the eye.



B. Indirect reflected exposure is diffuse and thus, less dangerous.

Fig. 6. Direct and indirect beam exposure to eye.

6.3. Maximum permissible exposure

The degree of ocular hazard following direct intrabeam and indirect reflected exposures has been published in the maximum permissible exposure (MPE) tables. MEP has been correlated with the wavelength of the beam and exposure duration. In clinical practice, only intrabeam tables seem relevant, as indirect beams are diffuse and thus, less hazardous. However, a collimated CO_2 beam, even if reflected from a convex and large surface, may retain sufficient power to cause ignition of the anaesthetic tube.

Based on ocular hazard, MPE tables classify lasers into four categories. Class 1 represents the least hazardous and Class 4, the most. All ENT lasers belong to Class 4, except for the HeNe laser, which serves as an aiming beam. The laser is graded as Class 2, *i.e.*, transitory ocular exposure to the beam carries no risk, but gazing at the beam voluntarily is not advised. The full classification of lasers is described in Chapter 2.

While assessing the hazards of intrabeam viewing, consideration should be given to the converging effect of the eye's lens. The 'ultimate' spot size striking the retina will be extremely small and sharply focused. Thus, it carries an enormous concentration of power and is potentially capable of damaging the macula causing permanent blindness.

6.4. Protective eyewear

Protective eyewear must be worn in the event that MPE is exceeded. This eyewear should fulfil the following criteria:

- the glass should attenuate the laser beam sufficiently so that direct exposure does not exceed MPE; and
- it should be able to resist the high-energy exposure without being perforated or shattered.

While manufacturers normally comply with the first criterion, they rarely guarantee the second (Health Devices, 1993; McKenzie and Carruth, 1984).

The protective eyewear is wavelength-specific, and care should be taken to ensure that the correct glasses are being worn where more than one wavelengths is available in the operating theatre (Rockwell and Moss, 1989). The glasses should be of a high quality, complying with ANSI standards (Sallavanti, 1995), so as to ensure that the surgeon's visual acuity is not impaired (Teichman *et al.*, 1999).

6.5. Co-axial microscope beam delivery

When using the CO_2 laser beam co-axially with the microscope, the surgeon's eyes are protected by the microscope optics, and therefore there is no need to wear additional protective eyewear (Sallavanti, 1995). When using the CO_2 laser beam with a hand piece, protective eyewear is of course compulsory for the surgeon.

7. Dedicated anaesthetic technique

Laser surgery on laryngeal pathology requires a dedicated anaesthetic technique since it involves the risk of intraoperative fire, and the most serious fire hazard occurs when a flammable anaesthetic tube suffers either a direct or an indirect strike. Cases of fire or of the explosion of combustible material have continued to be reported in the literature since laser surgery was first introduced into clinical practice in the 1970s (Snow *et al.*, 1976). These range from minor burns to catastrophic fires involving patient fatalities (Fried, 1984).

Patient and staff safety from fire hazards in the airway is the joint responsibility of the anaesthetist and the surgeon, since both teams require concurrent access to the airway. Neither speciality can claim priority in routine cases. However, when the airway is in jeopardy, surgery must be stopped and the anaesthetist given priority.

Therefore, it is obvious that a close working relationship is an essential part of any laser set-up. This teamwork starts when the surgeon examines the patient and advises laser surgery. Apart from the surgical assessment of the lesion for laser management, the surgeon must also assess it from an anaesthetic point of view. The findings are then discussed with the anaesthetist. Any video recording, taken in the outpatient clinic, should be reviewed jointly. An estimate of the time required for surgery should also be discussed, for optimal anaesthetic control.

Laser surgery on the larynx requires a partnership between the anaesthetist and surgeon. If possible, surgery should not be undertaken in the absence of a 'regular' anaesthetist, for instance, during brief absent for holidays, etc. Although joint management is important in all laryngeal cases, there are two conditions that require most cooperation, debulking to avoid tracheostomy for acute laryngeal obstruction due to a malignant tumour of the larynx, and laser tracheo-bronchoscopy. In both conditions, the airway is severely jeopardised and the patient is in a life-threatening situation. Needless to say, very small children and babies, particularly premature cases, have their own requirements for expertise, in addition to fire safety. Some cases of recurrent respiratory papillomatosis (RRP), particularly in young children, also require a repetitive anaesthetic, and once again, joint long-term planning is useful.

In most laryngeal and lower airway management, the endotracheal tube is in the way. Diagnostic procedures rarely cause a problem, since they are usually of short duration. Surgery with cold instruments can be undertaken with a smallsized tube placed posteriorly, in the interarytenoid region. The therapeutic management of the airway with a laser requires some additional considerations:

- *Operative time:* some procedures can take the best part of an hour, *e.g.*, in extensive papilloma, or even longer, in some cases of cancer of the larynx. Manipulation of the equipment to ensure adequate surgical access during the procedure can be time-consuming but essential. Apnoeic anaesthetic techniques are unsuitable in such conditions.
- *Intubation with a flammable tube:* the presence of a tube made of flammable material in the larynx poses a potential fire hazard. A conventional rubber or plastic tube must be protected against direct or indirect laser strikes. Any kind of intra-operative fire is unacceptable, and therefore, any comparison of the fire hazard between red rubber and PVC is irrelevant! It is safer to use tubes made from laser-safe or laser-proof material.
- *Laser surgery in the lower airway:* laser surgery in the lower airway requires tubeless anaesthetic techniques.

The anaesthetic aspects are discussed in detail in Chapter 6. The following discussion covers the *surgical* viewpoint.

7.1. Flammable endotracheal tubes

Flammable endotracheal tubes must be protected by wrapping them with laser-proof material, or shielding them from laser strikes with wet saline pledgets. It should be noted that the protection offered is only as good as the method of application, and not the choice of material. The wrapping also increases the outer diameter of the tube and encroaches upon the surgical space, severely restricting access to the pathology. The following methods are used for wrapping the tubes:

- *Foil wrapping:* the oldest and most effective method is 12-mm aluminium tape (3M #425) (Sosis and Heller, 1988b), wrapped from the cuff to the proximal end of the tube, in a spiral fashion. However, wrapping may not be even and may expose the sharp edges of the foil, particularly at the curvature. Thus, the foil-wrapped tube may prove to be traumatic to non-target oropharyngeal and laryngeal structures. The foil wrapping also makes the tube somewhat rigid and unyielding to manipulation with the tip of the laryngoscope. Care must be taken to ensure that the sharp edges of the foil do not damage the vocal cords.
- The cuff of the tube remains vulnerable. Surgeons must exercise caution and protect the cuff throughout surgery with saturated cotton pledgets, which

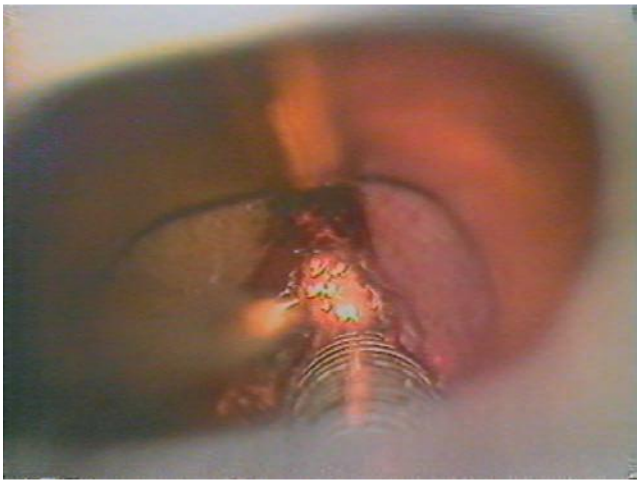


Fig. 7. Wet swabs inserted in the subglottic space can dry out and ignite. They should be periodically moistened, or removed and replaced.

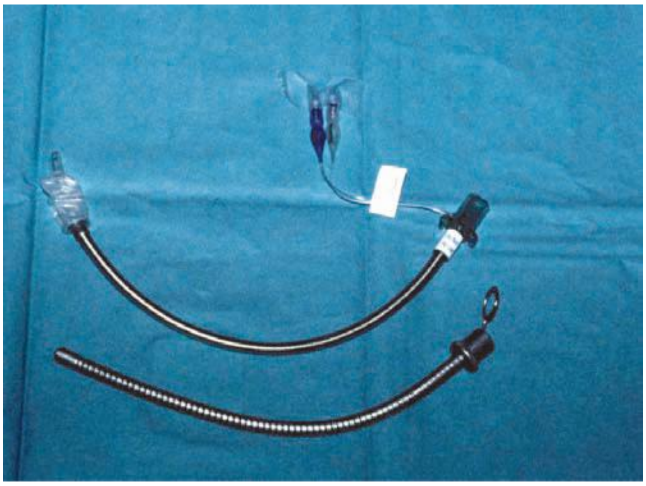


Fig. 8. Single use Mallinckrodt with cuff (top). Oswal-Hunton multi-use cuffless tube. (Photograph courtesy I. Morgan)

tend to dry up and flare (Fig. 7). A 10- or 20-ml syringe, filled with saline should always be available to dowse any flare and to keep the pledgets moist. As an added precaution, the cuff is filled with physiological saline tinted with methylene blue. Inadvertent punctures are indicated whenever blue fluid is seen leaking in the subglottis. The cuff does not ignite as the saline acts as a heat sink and absorbs the laser energy.

Oral intubation with a protected tube may be difficult in short-necked, obese patients and in very small children, due to the small glottic aperture.

Nasal intubation with a foil-wrapped tube is not possible since it invariably results in bleeding from the vascular nasal mucosa. Brief operative procedures can be undertaken with an unprotected nasal rubber tube advanced only up to the oropharynx, just short of the operative field. Once *in situ*, the tube is loosely secured and not tied with tapes – a deviation from standard anaesthetic practice. A loosely secured tube can be withdrawn instantly, in case of ignition.

It is necessary to ensure that foil-wrapped tubes are removed gently at the conclusion of the surgery, in order to avoid any trauma.

- *Merocel Laser-Guard™:* the Merocel Laser-Guard™ is self-adhesive, sponge-covered silver foil, which increases the outer diameter of the tube by 2 mm. The sponge must be kept constantly saturated with physiological saline: the Laser-Guard™ ignites if becomes too dry. Other materials have been proposed for protecting the endotracheal tube, including gauze (Sosis and Heller, 1988a).
- *Laser-Trach™*, adhesive copper foil covered with fabric which is kept wet with saline (Laser-Trach™) (Sosis *et al.*, 1996).

7.2. Metallic laser-proof endotracheal tubes

- *The all-metal tube:* the all-metal tube developed by Norton and DeVos (1978), and the Oswal-Hunton tube (Hunton and Oswal, 1985) are fireproof and cost-effective, but do not have a cuff (Fig. 8). The tube is comparatively unyielding and difficult to retain in the anterior larynx during surgery of the posterior lesions. Nasal intubation with the metal tube is possible by railroading it through a slit rubber tracheal tube passed endonasally and then withdrawn when the metal tube enters the oropharynx. The tube is then advanced into the larynx and the trachea.
- *The Mallinckrodt Laser-Flex tracheal tube:* the Laser-Flex tracheal tube has a factory-wrapped metallic shield. It is fire-safe for laryngeal work (Fried *et al.*, 1991), but is marketed with a single use specification and thus, relatively expensive. Should the cuff suffer inadvertent strike and lose its integrity, the Laser-Flex has a second distal cuff, which maintains the integrity of the anaesthetic circuit.
- *The Xomed Laser Shield tube:* the Xomed Laser Shield tube was initially made from silicone covered with aluminium powder. The second genera-

tion tube, Laser Shield II, includes a Teflon layer that coats the aluminium (Green *et al.*, 1992). For standard working conditions, these two models are effective. Xomed has also adapted this type of protection for high-frequency, jet-ventilation catheters.

7.3. Tubeless anaesthetic techniques

Spontaneous ventilation is only feasible for non-obstructive lesions and short procedures. During lasing, oxygen is stopped and smoke is evacuated (Aun *et al.*, 1990). Apnoeic anaesthesia with intermittent ventilation avoids the use of flammable material in the airways. However, since this method involves spontaneous oxygen desaturation, it is only useful for short bursts of surgical activity of between 90 and 120 seconds. A cumulative apnoeic period should not exceed ten minutes. It should be noted that spontaneous oxygen desaturation occurs much more quickly in children, in whom extra care is necessary (Cohen *et al.*, 1988).

8. Video monitoring and archiving equipment

Video monitoring is now commonplace in most modern theatres. Digital technology has not only improved the quality of image capture, but also has made it possible to record both moving and still pictures from an HD camera (e.g., Aida unit from Storz) attached to a microscope or an endoscope. In laser surgery, imaging has a special role to play. The laser technician can anticipate activation of the beam, by watching the HeNe spot on the video monitor. In the unlikely event of an accident, such as ignition of a swab or an anaesthetic tube, the technician can disable the laser instantly by hitting the large emergency knob, situated on the control panel of most lasers. Watching the monitor, the assisting nurse can help evacuate any excessive smoke with an additional cannula held in the vicinity of the surgical field. Video monitoring is particularly useful to the anaesthetist in optimising anaesthetic time in critical cases. Finally, valuable in-house training can be given to trainees, and more importantly, their work can be followed by their trainers in order to ensure sound training and patient safety. Archiving of operative procedures can be useful in medico-legal issues.

9. Dedicated laser instruments

In addition to the general standard instrumentation required for the procedure, dedicated laser surgery instruments are also necessary. During laser surgery, the products of vaporisation are released as smoke or vapour. Smoke is heavier than air and remains in the lumen of the laryngoscope or in the nasal cavity, completely obscuring any view of the surgical field. Therefore, it is necessary to remove the plume continually, and as effectively as possible, from the immediate vicinity of the surgical field in order to maintain surgical progress.

Dedicated laser instruments have a built-in suction cannula alongside the shaft. The cannula extends all the way to the 'business end' of the instrument so that the plume is removed as soon as it is released. For fibre-delivery lasers, an additional fibre channel is also incorporated. The diameter of this fibre channel is slightly larger than that of the optical fibre in order to offer some resistance, so that the fibre stays in place without any additional mechanism. Finally, in order to prevent reflection and to promote maximum dispersion of the beam (Wood *et al.*, 1992), the instruments are ebonised or sand-blasted. Sometimes, matt-finished instrument tips can be used as beam stops to protect the non-target tissue.

Newer endoscopes, and in particular laryngoscopes, are equipped with wall-integrated channels.

Laser-assisted surgery, particularly with the CO_2 laser, requires monopolar electrocautery to be readily available on the instrument trolley for haemostasis of vessels larger than 0.5 mm in diameter. Pledgets soaked in adrenaline solution (1:100,000) are useful for controlling oozing.

10. Advanced laser accessories

The CO_2 is the most versatile laser for ENT use. Until recently, lasers, and in particular the CO_2 laser, were essentially used for lesions of the larynx and trachea. Although these applications still exist, recent innovations such as various electromagnetic production modes, beam-guiding software, and refined optical instruments transmitting the beam from the laser arm to target, have extended their use to the ear and nose.

10.1. Continuous, pulsed and superpulsed waves

The initial CO_2 laser microwave was a continuous wave (CW). At a given power, it provided continuous output. The continuous exposure resulted in serious heating of the collateral, non-target tissue by conduction. In order to minimise the thermal effect, the pulsed mode was developed for the CO_2 laser (Sharpulse®). In the superpulse mode, very high energy, of the order of 400-500 W, is delivered with each peak, but over an extremely short period of a few nanoseconds. The peaks are interspersed with a rest period when no exposure occurs, allowing time for the tissues to cool down. Thus, there is no buildup of heat and, consequently, no diffusion to the surrounding non-target tissue. With the laser set in the superpulse mode (Superpulse®), the high peak energy enables char-free ablation of the tissue and, at the same time, the sparing of deeper, normal, nontarget tissue. The *average* power, which is preset during programming, is usually between 1 and 10 W.

10.2. The flashscanner

This miniature optomechanical system is compatible with all makes of CO_2 laser. It consists of two nearly parallel mirrors which constantly rotate at slightly different angular velocities, thereby rapidly varying the off-axis angle between zero and the maximal value. The CO_2 laser beam is deviated from its original direction when it is reflected from these rotating mirrors. By attaching a focusing delivery system, the CO_2 laser generates a small focal spot, which scans the tissue rapidly and uniformly, and covers a circular area with a preselected diameter within the focal plane. Newer generation flashscanners are operated by software integrated in the laser device. The software has various commercial names: 'Surgitouch' in ENT and 'Silktouch' in cosmetology (Chernoff *et al.*, 1995). The old name of 'Swiftlase' is now obsolete (Krespi and Ling, 1994d). The rotatory mode of the flashscanner makes the CO_2 laser an ideal tool for all indications requiring superficial vaporisation or abrasion, over a given surface. Each surface sweep of the beam vaporises a layer of tissue from 0.15 mm to as thin as 50 µm: this produces a genuine 'shaving' effect. Thermal penetration is less than 150 µm. The flashscanner is used in a number of applications, namely, tonsil ablation, surgery for snoring, tumour debulking, etc. (Krespi and Keidar, 1994b; Krespi and Ling, 1994d).

In addition to the rotatory mode, the beam can also travel along a linear or curved line of a given length (Cohen *et al.*, 1998). This software application, known as AcuBlade® (Figs 9 and 10), is a flashscanner adapted for CO_2 laser-assisted microincision and microdissection. The beam penetration, calculated according to the laser interaction with living tissues, is adjustable. Thus, the width of the incision line obtained is the same as that achieved with the Acuspot micromanipulator, *i.e.*, 250 µm for a focal distance of 350 mm.

Flashscanner-guided incisions are more accurate than those obtained manually in the single pulse mode. The incision length can range between 0.5 and 3.5 mm, and the depth between 0.5 and 2 mm. The incision and dissection time required is less than that with the simple, handguided beam. The coagulation depth of less than 50 µm does not invalidate meaningful histological examinations. The authors believe that the AcuBlade® has a promising future in laryngeal microsurgery and, more particularly, in phonosurgery.

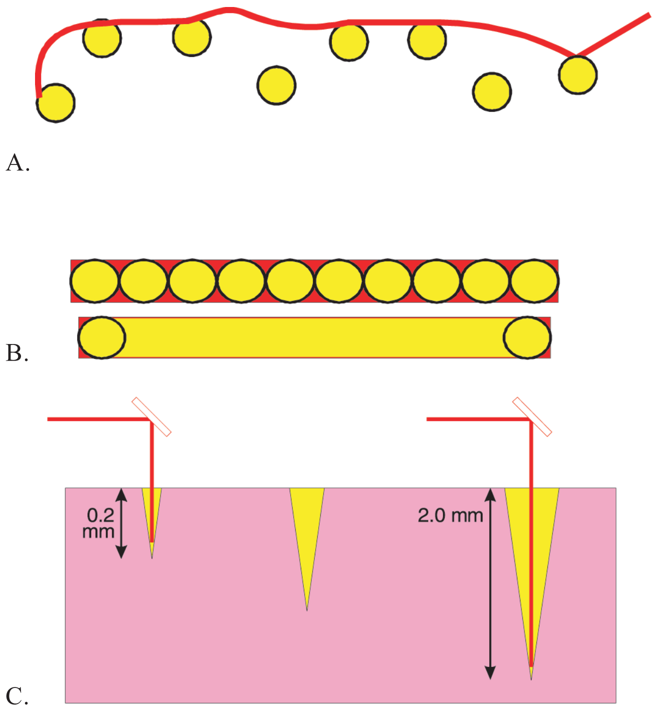
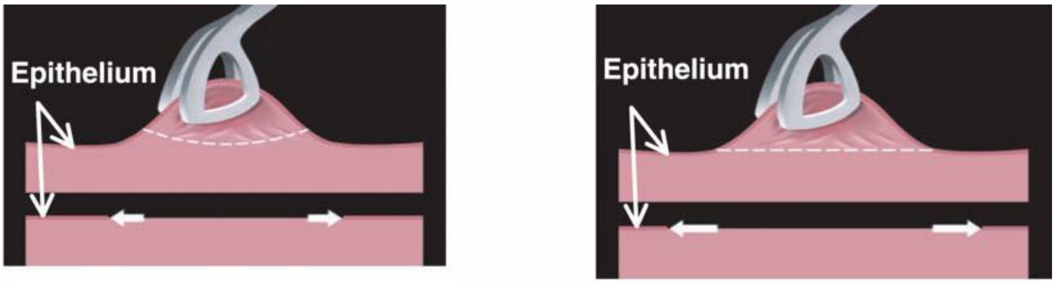


Fig. 9. The AcuBlade versus standard technique – Acublade provides a linear incision with a predetermined depth of cut. A. With standard technique, the incision line is ragged since the incision is undertaken with single shots. B. The incision line with AcuBlade is smooth since it is taken with continuous exposure in superpulse mode. C. The depth of incision with AcuBlade can be determined and ranges from 0.2-2 mm, with less than 50 µm thermal damage.



A. Less epithelium removed with standard spot, curved incision.

B. More epithelium removed with AcuBlade, linear incision.

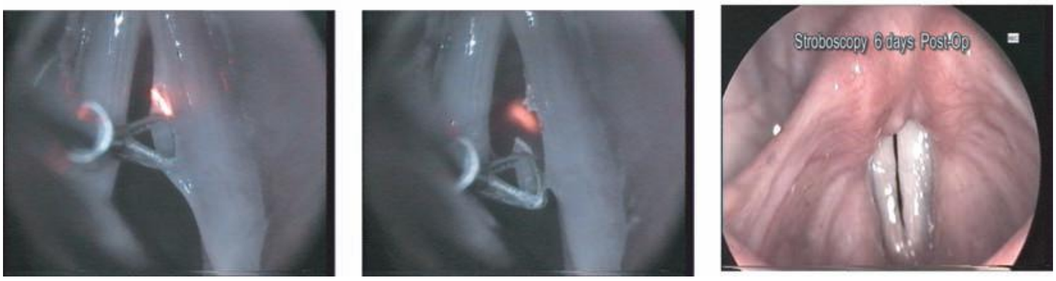


Fig. 10. The AcuBlade versus standard technique – Acublade provides a neat linear incision.

10.3. Acuspot micropoint micromanipulator

Although possible, laryngeal microsurgery was difficult because the smallest spot size provided with earlier micromanipulators was a good 700 μm in diameter at a working distance of 400 mm (Remacle *et al.*, 1999a; Shapshay *et al.*, 1990). The micropoint micromanipulator (the 712 Acuspot, Sharplan; Fig. 11) concentrates the delivered energy on a smaller surface, thus achieving the same effect, but with less pulsed power. This results in reduced thermal conduction around the target, improved macroscopic incision, and consistent microscopic cellular vaporisation. Via a set of mirrors, the micropoint micromanipulator (Ossoff *et al.*, 1991) provides a 250-μm diameter beam for a working distance of 350 mm. The combined improvement provided by the micropoint micromanipulator and the Superpulse® electromagnetic wave facilitates incision and dissection of the vocal fold epithelium with greater precision and shallower thermal damage.

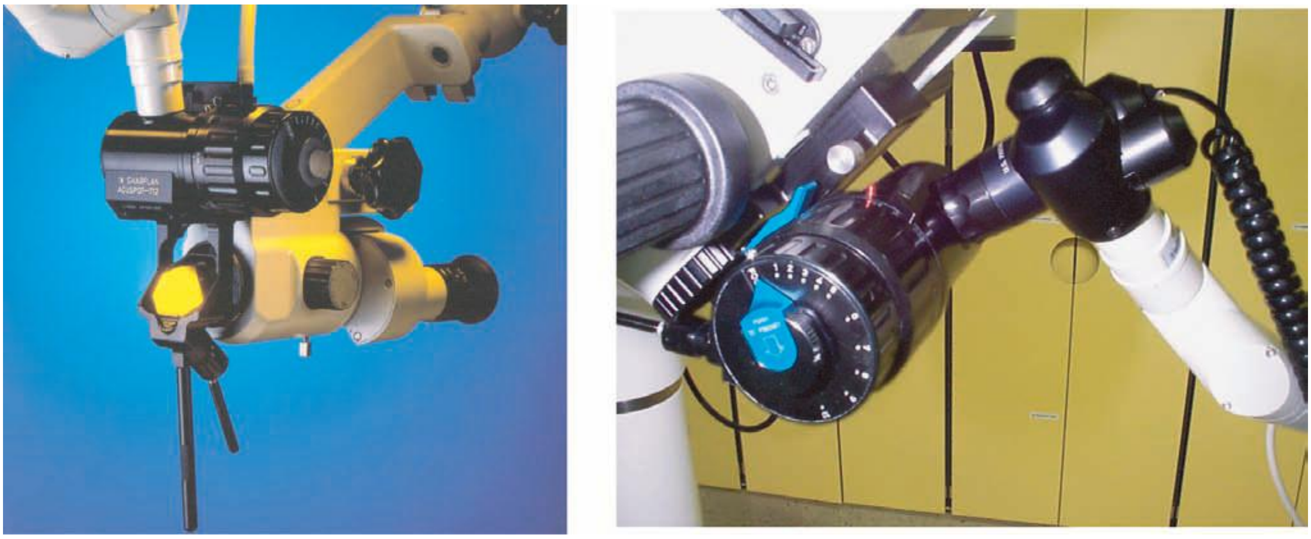


Fig. 11. The 712 Acuspot (Sharplan).

10.4. Hand piece

The laser arm can be connected to a hand piece, which comes in different lengths. A 225-mm hand piece is most useful and can be fitted with various tips. A straight, large hand piece with a side-firing tip is suitable for tonsil vaporisation. A slim side-firing hand piece is used for turbinoplasty. For surgery for snoring, an angled tip facing upwards and ending in a backstop is convenient (Fig. 12). The 225-mm hand piece has a smoke evacuation channel and a nitrogen flux channel for cooling and dispersing the debris. The hand piece can be used in focused or defocused mode (Kamami, 1994; Krespi and Ling, 1994e).

10.5. Waveguides

It is possible to secure flexible CO_2 waveguides within metallic flexible channels and to connect them to a hand piece. These metallic guides are available in different shapes and angulations. Although they are mostly used for rhinology applications, they can also be employed in subglottic and tracheal surgery (Schmidt *et al.*, 1995).

10.6. Otolam

The Otolam is a specially adapted hand piece for CO_2 laser-assisted tympanic membrane fenestration. Combined with a flashscanner and connected to the laser arm, the Otolam has a video camera attached at its proximal end to monitor the procedure. The Otolam can be safely used in children and adults under local anesthesia (Fig. 13; Brodsky *et al.*, 1999). Its use is described in detail in Chapter 35.

10.7. Tracheobronchial surgery adapter

Up until 1974, the CO_2 laser was adapted for the bronchoscope via a 15-cm^3 box containing a beam-reflective system (Strong *et al.*, 1974). However, a smaller and more practical model has replaced this cumbersome prototype. Directed into the broncho scope by a highly reflective mirror, the CO_2 laser is focused at the distal end of the bronchoscope by a lens. Examination of the target tissue through an eye piece is made possible by means of a dichroic mirror (beam splitter). The mirror transmits both the visible light and the CO_2 wavelength at 10.6 µm, totally and completely. Two outer screws ensure adjustment of the beam alignment. The system is constantly being improved: a joystick to direct the beam has been added, and a coated quartz crystal has replaced the dichroic mirror. The current model is equipped with a protective mirror, interposed between the coupler and the bronchoscope, which restrains laser plume. This mirror requires periodic cleaning. The coupler can be adjusted for different focal distances (Ossoff and Karlan, 1982).

A set of bronchoscopes has been specially manu-

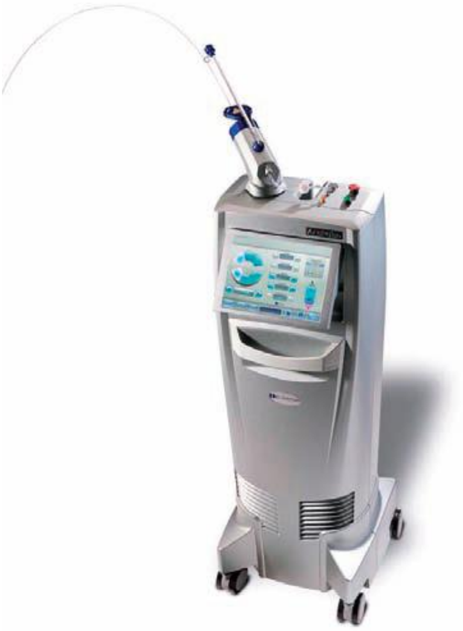
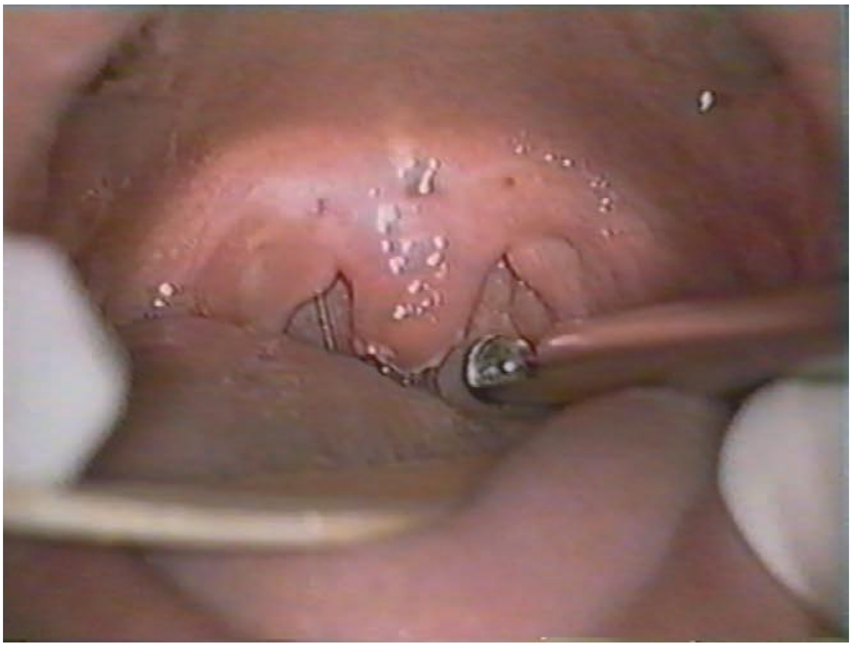


Fig. 12. Acupulse WG CO_2 laser.



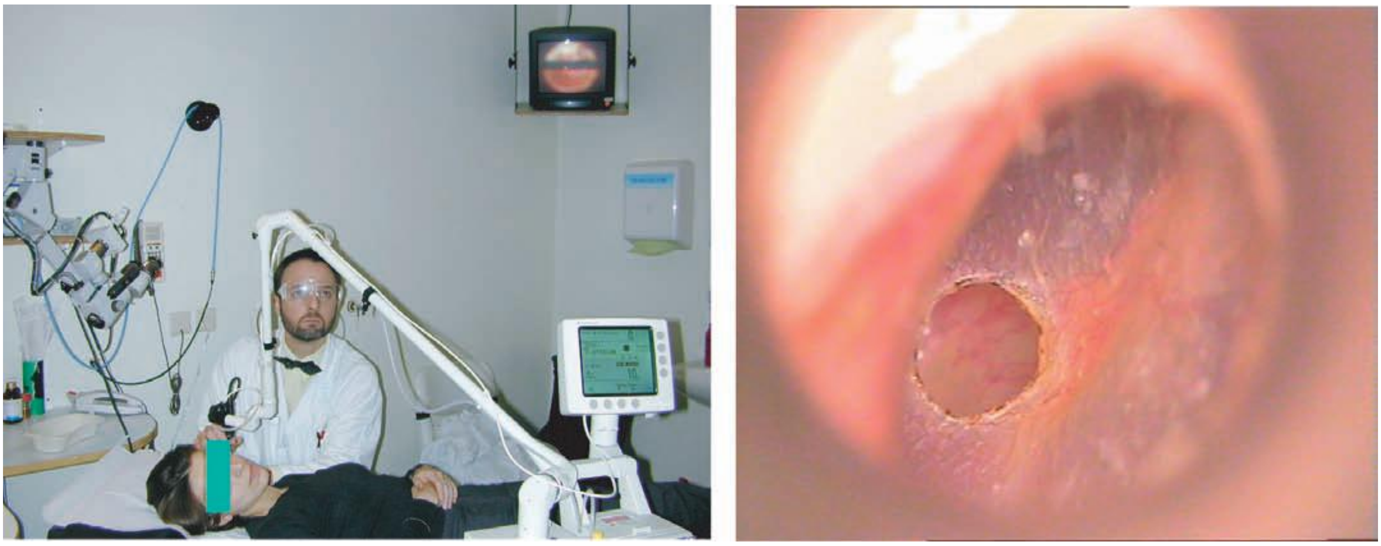


Fig. 13. Transmission of CO_2 laser beam via articulated arm (procedure: Otolam® myringotomy).

factured for laser-assisted surgery (Ossoff and Karlan, 1983a). These bronchoscopes have two channels, one for smoke evacuation, the other for various ventilation modes including high-frequency jet ventilation (HFJV), which is particularly well suited for this type of surgery. The smallest laser bronchoscope has an outer diameter of 3.5 mm (Garabédian *et al.*, 1990). The inner wall of the bronchoscope is sand-blasted to ensure maximum beam dispersion should the beam strike it.

Despite considerable improvements, some cases still pose problems. The beam does not always emerge in the centre of the distal aperture of the bronchoscope. Central emergence seems to depend on both the position of the laser arm and the quality of alignment of the mirrors within the arm.

Certain distal lesions are inaccessible to rigid bronchoscopes. Paediatric bronchoscopes are sometimes too large for the management of small children and premature babies. The CO_2 laser waveguides have solved this problem to a certain extent (Blitzer and Krespi, 1998). They can be passed through a standard paediatric bronchoscope equipped with a telescope and operating channel.

Fibre-guided lasers, such as the YAG or the diode lasers can pass through fibrescopes (Shapshay *et al.*, 1985).

The flashscanner can be interposed between the laser and the coupler described in paragraph 10.2 above (Raif and Zair, 1993). The flashscanner-operating software adjusts the central alignment of the beam within the bronchoscope. This software has facilitated adjustment of the alignment so that the beam emerges in the centre of the distal end of the bronchoscope lumen.

11. Instrumentation for various laser procedures

Surgical skills and surgical hands vary considerably. An instrument idealised by one surgeon may not be appealing to another. This section will only describe the principles involved in selecting an instrument for a particular type of laser procedure. It will not go into the details of a number of individual items; these are covered in the appropriate sections. The reader is advised to consult catalogues, select instruments, and have them on trial, before committing to a purchase. There are two basic requirements for most instruments for use in laser surgery: a built-in suction channel and a non-reflective finish.

11.1. Laser instruments for laryngeal surgery

Laryngeal lesions requiring phonosurgery are usually small. The surgical procedure is short, and does not generate much smoke. Phonosurgery can be undertaken using a conventional laryngoscope with an aspiration channel. Oozing and bleeding is also minimal, and can be controlled with adrenaline-soaked pledgets held against the bleeding area for a few seconds.

For bulky and protruding benign lesions, as well as for endoscopic cordectomy and arytenoidectomy, wide exposure of the surgical field is necessary for orientation and surgical access. Specific laryngoscopes have been developed for wide exposure of the target. A laryngoscope with expanding proximal and distal ends is useful, and a variety of designs are available commercially. Two adult and one paediatric model will cover most requirements. A variety of microforceps with aspirator and monopolar coagulation are also available (Remacle, 1991).

Other dedicated instruments, such as cord rollers, operating platforms and laryngeal mirrors, are available (Ossoff and Karlan, 1983b) but are rarely required.

11.2. Laser instruments in oral surgery

The hand piece for taking the beam into the oral cavity, together with its various tips, is an essential instrument. It is also extremely useful to have a tongue depressor fitted with a smoke evacuator. Tongue depressors with retractors, angled to the left or right, for use on anterior tonsillar pillars, are also available (Remacle *et al.*, 1999b).

11.3. Laser instruments for rhinology surgery

A detailed description of endoscopic and microscope approaches for endonasal laser surgery can be found in Chapter 20. CO_2 laser waveguides or CO_2 hand pieces, fitted with thin side-firing tips, are useful for turbinate surgery (Krespi *et al.*, 1994a). However, these are rather bulky compared to optical fibres. Fibre transmissible lasers are more useful and can be used in conjunction with an endoscope to tackle nasal pathology located almost anywhere in the nasal cavity.

11.4. Laser instruments for otology surgery

The Acuspot is an essential device for middle ear laser surgery. Combined with the flashscanner, it allows calibrated delivery of energy for stapedotomy and tympanic membrane fenestration (Silverstein *et al.*, 1996). For office-based procedures, Otolam is the instrument of choice for tympanic membrane fenestration (Garin and Remacle, 1999). With the exception of their non-reflective characteristics, the otoscopes and microinstruments used in laser ear surgery have no particular features. Some otologists prefer the fibre-guided argon or KTP laser (Gherini *et al.*, 1993).

12. Transoral Robotic Surgery for laryngeal lesions

Recently, transoral robotic surgery (TORS) has been introduced, mainly for oropharyngeal and supraglottic malignant lesions. Although it has certain advantages over conventional surgical methods, the technique requires a dedicated space, a high capital outlay and certainly, training at an advanced level with high skill demand. See chapter 65 for further reading.

13. Conclusion

Laser surgery requires a concerted approach by the operating team. The smooth operation of the laser list can only be achieved by planning the theatre layout, using dedicated laser instrumentation, training personnel and, above all, by developing a keen vigilant culture to avoid accidents and hazards, some of which can have fatal consequences.

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MCQ – 4. Equipment and instrumentation

1. Based on ocular hazard, lasers are classified into four categories. All ENT lasers belong to
    a. Class 1
    b. Class 2
    c. Class 3
    d. Class 4

2. Which is the specially adapted hand piece for CO_2 laser-assisted tympanic membrane fenestration?
    a. Otolam
    b. Flashscanner
    c. Micromanipulator
    d. Acuspot

3. Most *dedicated* optical fibres marketed for *single* use can be used
    a. With any laser but not the CO_2 laser
    b. repeatedly if the tip is properly cleaved when deteriorated
    c. In the same patient for repeat procedures at intervals
    d. In a number of patients if properly sterilized between uses
    e. All of the above

4. Plume produced by laser strikes
    a. Is a nuisance
    b. Is a health hazard for operating theatre personnel
    c. Is flammable at high temperatures
    d. Should be removed by hospital central evacuation system
    e. Should be removed by specialized evacuator

5. The following flammable substances / materials will *ignite* at high temperature if struck with a laser beam
    a. Oxygen
    b. Nitrous oxide
    c. PVC anaesthetic tube
    d. Laser safe Laser-Flex tracheal tube
    e. Laser plume

Chapter 5

Theatre protocol and surgical technique

V. Oswal and M. Remacle

1. Introduction

Health care is one of the most fertile grounds for the introduction of technical advances. The latter years of the last century witnessed a surge in hi-tech equipment, such as the laser in the operating theatre. The first-generation CO_2 laser, the size of a washing machine, was introduced in the 1980s, and soon became the workhorse of ENT surgery. Co-axial microscope delivery required it to be close to the surgeon. Fibre-guided lasers were acquired by many institutions in the 1990s, with their long thin fibre crossing haphazardly from the machine to the surgeon's hand and then to the patient's operative field. Moreover, they are hardly visible, and easily get caught in the drapes and other instruments.

In the modern ENT theatre, the pressure for floor space around the head end of the operating table is considerable, and the noise level from the various machines is tiring. The cost economics of health care systems requires the rapid turnover of cases. As more gadgets are introduced, nurses' training lags behind, and their work continues more by proxy than by design. The first decade of the twenty first century is witnessing the march of the robots in to the operating theatres. More than ever, therefore, it is necessary to have a systematic approach to the random development spanned over the past few decades. This chapter hopes to address some of these issues, the peculiar needs of robotic surgery are addressed in Chapter 65.

2. Operating theatre protocol for laser surgery

Right at the outset, it has to be recognised that the use of lasers in the operating theatre poses a hazard to the whole of the operating team, as well as to the patient. Clinicians, obviously due to the nature of their work, have a unique dispensation; they are allowed to point and activate the laser at a person – a scenario which is totally prohibited where industrial lasers are in use. This dispensation also carries with it a legal obligation that the beam be used only on its intended target and everything else is regarded as non-target and protected against inadvertent or accidental laser strike. Chapter 3 sets out both legal and professional requirements to ensure safe use of laser, and is aptly headed, 'First Do No Harm'.

In most hospitals, laser surgery is carried out in multi-purpose, general, operating theatres. The concept of a dedicated laser theatre suite, advocated in the 1980s, did not gain recognition because of costs and the diverse multidisciplinary laser requirements. Cost considerations also meant that, in the future, laser machines would have to be shared by various specialities. This would entail operating in unfamiliar surroundings. A welldeveloped laser protocol will go a long way to ensuring smooth and safe surgery for the laser team, and, more importantly, for the patient.

Unlike conventional surgery, laser energy is delivered as a beam of light. The beam travels through the air from its exit aperture to the target tissue.

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The beam of the CO_2 laser remains collimated and retains its energy over a considerable distance. Although the beam is pointed in the direction of the target, there is always a risk that it may be reflected by the polished surfaces of the instruments. A stray beam can travel in any direction, depending on the nature of the reflecting surface. Thus, the entire operating theatre is a potential laser-risk area.

Fibre-transmissible lasers are comparatively safe since they transport the energy directly to the vicinity of the target. The emerging beam is divergent, and thus loses its energy within a short distance from the exit point. However, fibre-transmissible beams can escape through a damaged fibre and therefore remain a source of risk.

Laser surgery results in considerable pollution of the operating theatre with smoke and vapour. The operating theatre must be well ventilated and equipped with dedicated smoke evacuators. The electrical installation and plumbing must be laser-proof and safe. Reflective or polished materials must be avoided. Windows are blacked out during lasing and doors kept closed in order to protect the staff in adjacent rooms and passageways. The other operating theatre equipment must not interfere with the use of the laser or microscope. Cables should not touch or press against the laser or its arm.

The most serious concern is the potential for eye damage and the ignition of flammable material. This risk can be minimised by certain modifications to existing operating theatres or by incorporating them in new theatres.

2.1. Illuminated warning signs

All entrance/exit doors should be marked with a warning sign, indicating that a laser is in use and that entry is only permitted to authorised persons wearing protective eyewear. The American National Standards Institute's (ANSI) approved warning sign indicates the wavelength, power, and laser class. If a number of different wavelengths are being used in the same theatre, then the sign also indicates the type of laser being used. This warns the staff to wear the appropriate protective eyewear. Certain operating theatres have entrances with flashing lights that state 'laser in use'. These lights are linked to the laser machine and light up automatically when the active beam is in use.

2.2. Protective eyewear

Wavelength-specific eyewear is provided for all staff working in the theatre during a laser session. It is the laser user's responsibility to ensure that the correct eyewear is being worn before activating the therapeutic beam.

2.3. Fire extinguishers for electrical fires

The use of water to extinguish an electrical fire is inappropriate. A fire extinguisher containing CO_2 gas or dry powder, together with a fire blanket, is positioned in close proximity to the main entrance door of the operating theatre in order to tackle any electrical fires.

3. Laser protocol

3.1. Laser protection adviser

In the UK, the employer receives suitable advice regarding the safe installation and operation of the laser from a laser protection adviser (LPA), who is usually the radiation protection officer of the Medical Physics Department. The LPA does not have specific safety responsibility for individual laser sites.

3.2. Laser safety officer

The responsibility for a particular laser setting lies with senior qualified nurse or senior operating department practitioner (ODP), who is designated laser safety officer (LSO). The LSO formulates local rules and ensures compliance within a specific local setting.

3.3. Laser key holder and laser register

The laser key holder (LKH) is the LSO or the deputy in charge of the theatre. The key is securely stored together with other keys in a designated area with restricted access. A register of any surgery involving lasers is also maintained, which provides a good reference for laser parameters used for any particular procedure.

3.4. Laser technician

A competent and trained laser technician (LT) is in charge of the laser during the session. He or she is not necessarily a nurse, but could be a health care assistant or senior ODP with appropriate training. The LT connects all the monitoring, laser, and suction equipment, and carries out pre-session checks as follows:

- *Test for misalignment of the CO_2 laser beam:* Since the CO_2 laser beam is invisible, a second low power helium neon (HeNe) laser, which emits in the visible part of the electromagnetic spectrum, is also available in the laser machine.

  The visible red HeNe spot is used as an aiming beam on the target. If the superimposition of the two beams is accurate, then the CO_2 beam will strike the target at the same spot as the HeNe beam. However, the two beams may be misaligned due to movement of the precision mirrors in the articulated arm, and therefore, it is necessary to check the alignment for accuracy prior to each surgical session. Testing is carried out by firing a test shot onto a wooden spatula placed on a wet towel (Fig. 1). If the two beams are misaligned, the test has failed and the laser must not be used.
- *Optical fibre:* a visible inspection of the optical fibre is carried out to ensure its integrity. The emerging beam must be intense and circular. A test fire should produce the anticipated burn for selected laser parameters. When a reusable fibre is not cleaved properly, the emerging beam is distorted and lacks concentration of power.

  The fibre must be cleaved again and used only when the spot is circular.
- *Performance of the laser:* a practical way of ensuring peak performance of the laser is to test-fire a perspex block (Fig. 2) and to note the date of testing. Serial tests are carried out periodically, compared with the initial result, and stored. Any loss of power indicates that service is required before the scheduled date.

Following the equipment check, the LT sets the appropriate laser parameters for the procedure to be carried out, and puts the laser in stand-by mode. He or she also ensures that the correct eyewear is available for the particular wavelength to be used during the session.

The technician is also responsible for ensuring that activation of the beam only takes place when the beam is directed towards the target. For example, in endonasal nasal surgery, every time the fibre cannula is withdrawn from the nasal cavity by the surgeon for assessment of the procedure, the technician should turn off the active beam, independent of any such instructions from the surgeon. Likewise, he or she should inactivate the beam if any of the operating personnel notice anything untoward, such as non-target strikes (tangentially on the lips, teeth, etc., in laryngeal surgery). Such events may easily go unnoticed by the surgeon, whose attention is inevitably focused on the procedure.

3.5. Laser register

A laser register contains the names of all theatre personnel authorised to take part in laser sessions, following attendance and certification at a recognised course.

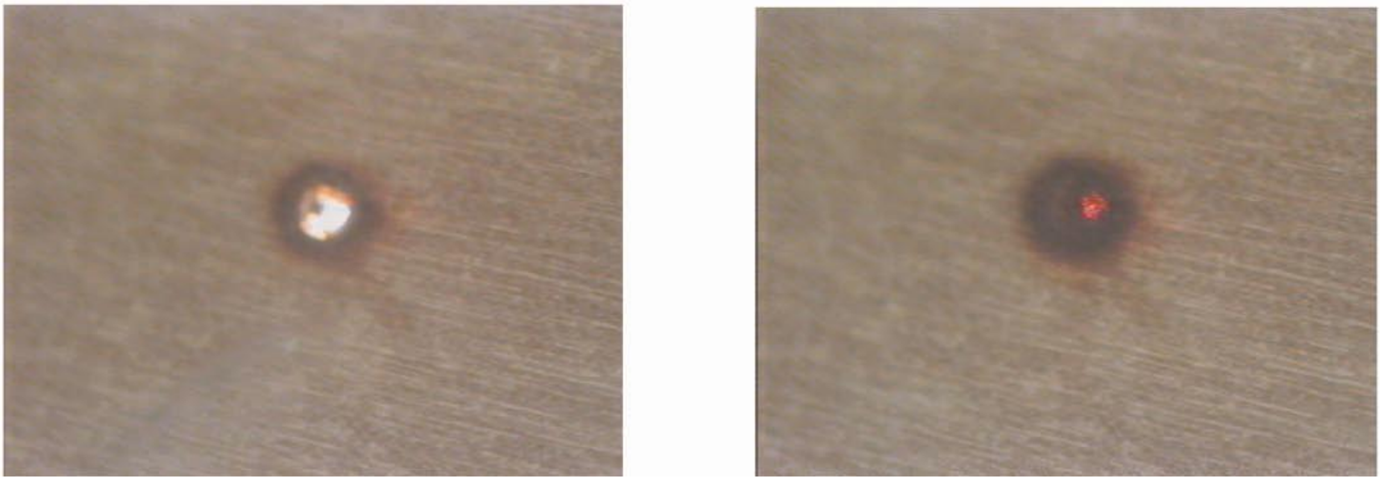

Fig. 1. Alignment of the invisible CO_2 beam and visible HeNe beam is checked by striking on a wooden spatula prior to each laser session.

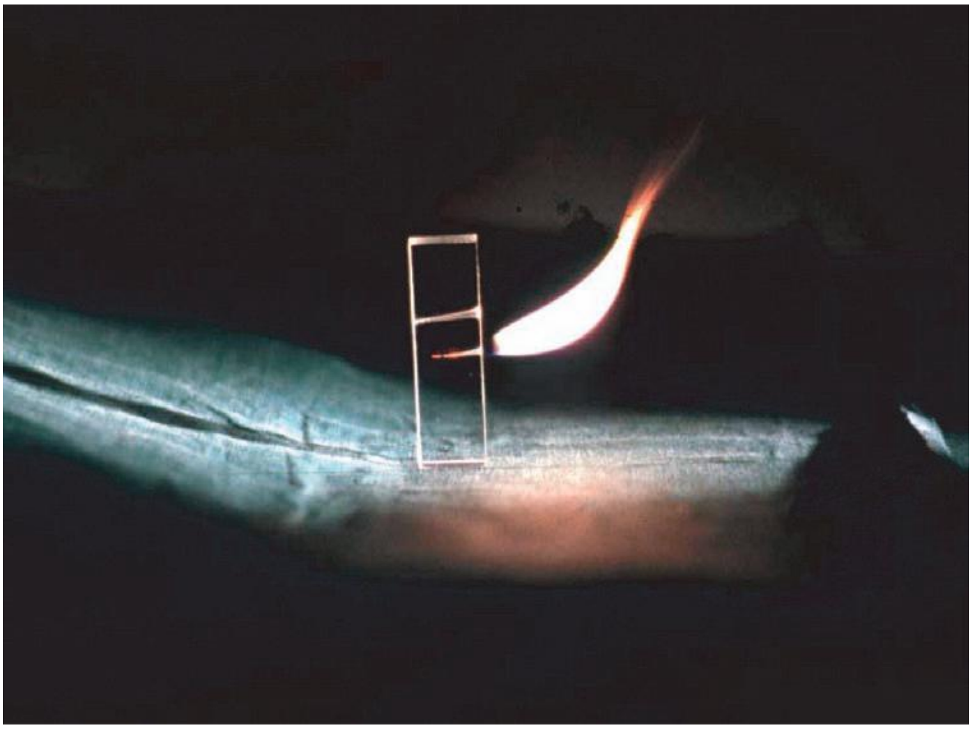

Fig. 2. Laser strike on block of perspex. (Photograph courtesy I. Morgan)

3.6. Laser maintenance

In recent years, lasers have become much more reliable. In particular, the introduction of the sealed tube in CO_2 laser technology has eliminated the need for refilling the laser gas mixture. In order to verify the actual power output compared to the theoretical power output, as well as to verify alignment of the beams, the authors advocate biannual inspection of the equipment by competent engineers.

3.7. Laser malfunction

There will be instances where the laser malfunctions during a procedure. Standard surgical instruments should be readily available in the event of laser malfunction.

3.8. Spot size

It is necessary to appreciate, particularly during phonosurgical procedures, that the spot size of the visible HeNe beam bears no relationship to the spot size of the invisible infrared CO_2 laser beam (Fig. 3).

3.9. Laser quality control

In the USA, all lasers must comply with the rules established by the Center for Devices and Radiological Health, a division of the Food and Drug Administration. In Europe, the Medical Devices Agency has a similar function. The classification of lasers (Chapter 2) is based on the relative degree of hazard during their use. The greater the hazard, the greater the risk and, therefore, the more stringent the safety requirements. The manufacturer has to place the laser in one of four risk categories. Each category has specific safety rules. Both the class and the relevant protective eyewear must be clearly indicated on the equipment. Most medical lasers belong to Class 4 and are potentially dangerous. Incorrect usage can result in burns or cause fires. All medical lasers are equipped with a lock and key. As stated earlier, only authorised personnel should have access to the key.

4. Staff training

Adequate training in the safe operation of the laser and the continuous vigilance of all those concerned with the laser list will minimise the danger

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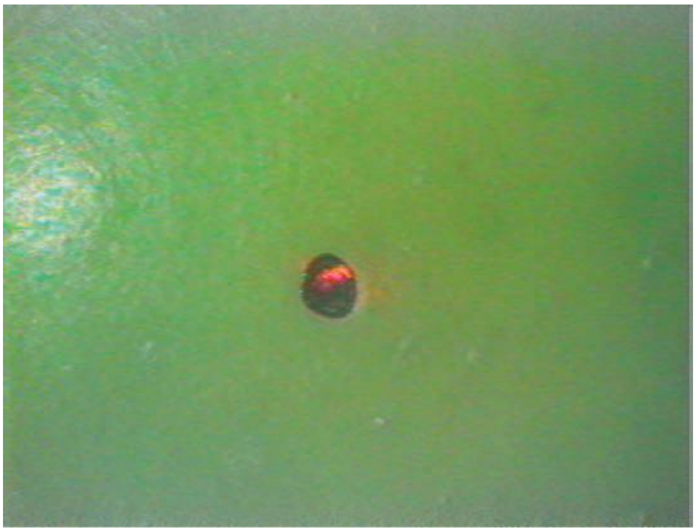

Fig. 3. CO_2 laser beam strike on an apple. The visible HeNe spot size may not always indicate the extent of the laser burn by the invisible CO_2 beam.

to patients and personnel during laser usage. Until recently, the surgical training of young doctors was self-initiated and peer-led. Some standardisation was introduced into the UK with the establishment of the Specialist Advisory Committee (SAC) in the 1970s. Nevertheless, self-initiated, peer-led training continued, even though the surgical advent of minimally invasive surgery, keyhole surgery, and laser surgery required more refined surgical skills. In the USA, the long-established programme of accreditation only required a small additional step in order to include credentialised laser training as a prerequisite for laser usage. Ossoff (1986) proposed a minimum curriculum of 16-20 hours of laser tutorials, with 50% of the time being allocated to hands-on training. However, in most countries, including the UK, there is no compulsory requirement to undergo formal laser training or any other specialised training, such as functional endoscopic sinus surgery, despite the abundance of training opportunities provided in well-run courses.

There is no doubt that the surgical technology of modern health care is more demanding and, when things go wrong, more unforgiving. The lack of suitable training has produced an array of disasters, such as fatal anaesthetic tube ignition following inadvertent laser strikes.

The authors have had the privilege of running laser courses over the years, and the following is an account of the experience gained from evaluation of these courses by the participants.

The courses comprise didactic tutorials on all aspects of laser technology, and live laser surgery and hands-on demonstrations on animal tissue. At the end of the daily activities, small group discussions and break-up sessions provide a proactive discussion platform for both the participants and the faculty. Close circuit television (CCT) with two-way audio facilities demonstrates live laser surgery in a range of pathologies. Monitor-controlled, supervised, hands-on biological tissue training in a simulated environment ensures the complete learning experience.

Similar but less intensive courses are run in the UK for nurses at the institution of one the editors (VO). Anaesthetists' training in laser anaesthesia is undertaken as part of their general anaesthetic training programme, leading to accreditation.

5. Laser-induced accidents

During the past 20 years, the number of lasers being used in the medical field has multiplied: argon, KTP/532, CO_2, neodymium:YAG, Er: YAG, holmium:YAG, THC:YAG, excimer, gold vapour, copper vapour, mercury vapour, pulsed dye, tunable dye, diode, Q-switched, free electron, the list seems endless. Delivery devices (optical fibres, waveguides, contact tips) and technology pertaining to beam transmission have also proliferated (Kuriloff, 1998).

A lack of knowledge in laser wavelength physics, laser interaction with living tissue, and laser treatment indications can lead to potential accidents.

Laser use should comply with several easily enforceable rules (Haug *et al.*, 1993). Non-compliance with these rules is the cause of most accidents (Ossoff, 1986). The accident rate is low in institutions complying with the ANSI rules (Sliney and Wolbarsht, 1980). Healy *et al.* (1984) report a complication rate of 0.2% in 4416 procedures; Ossoff (1986) describes a 4% rate; and Brodman *et al.* (1993) report a 9% complication rate in a study investigating laser-assisted gynaecological procedures performed by junior residents under the supervision of senior residents, despite the juniors having undergone previous training. In all cases, human error is a causal factor (Fulton, 1998; Grossman *et al.*, 1998). Current devices are perfectly safe with respect to energy parameters. Safety is further improved with software that constantly monitors the maximum energy limits allowed (Canestri, 1999).

Laser-induced hazards can be classified into the following categories:

- damage caused unintentionally by laser strikes on biological but non-target tissue, such as corneal or retinal eye injuries, skin and mucosal burns;
- hazards caused by laser strikes on non-biological material such as the anaesthetic tube and draping material;
- side-effects due to laser by-products such as laser-generated plume;
- laser malfunction such as electric shock.

Although experience has proved that these events are improbable during standard surgical practice, we must always ensure that any potential for them is minimised by attending to the details of work settings, surgical procedures, equipment maintenance, and quality control. Complacency in any of these areas could lead to a serious incident that, in turn, could discredit the laser in the eyes of operating personnel and public alike (Santos *et al.*, 2000). Certain countries have published standards for laser equipment and its use in medicine (ANSI 136.1, 1980; 136.3, 1985; BSI, 1983; Mohr *et al.*, 1984; Kuriloff, 1998; OSHA, 1995; PHS-FDA, 1994).

The ANSI recommendations (1985) include organising a laser safety committee and appointing an LSO. The safety committee usually encompasses a multidisciplinary team of doctors, nurses, biomedical engineers, and administrative staff. The committee meets regularly in order to establish and develop adequate protective measures and to organise the in-house hospital training for the management of laser-induced accidents (fires, burns, explosions, etc.). The LSO ensures that the committee's proposals are enforced. All incidents must be reported to and assessed by the committee, which in turn makes the appropriate corrective decisions.

6. The laser surgeon

Prior to commencing surgery, the surgeon inspects the laser equipment. In the specific case of the CO_2 laser, the aiming beam (HeNe) and the treatment beam (CO_2) must be co-axial. The surgeon tests the laser's impact on a wooden tongue depressor placed on a wet towel. If the two beams are not precisely aligned, the operation must be rescheduled or conventional instruments used.

An electrical mono- or bipolar scalpel should also be at hand. In order to avoid any fire hazard, flammable liquids (ethyl chloride, acetone, alcohol) must be removed during lasing. Whenever possible, paper drapes should be avoided. Soaked cotton pledgets should be available for protecting non-target tissue. During lasing, the use of pure oxygen must be avoided when flammable material is present within the airway.

7. Theatre layout for laser surgery

These days, the operating theatre has become a crowded place, with an increasing array of bulky hi-tech and monitoring equipment. In addition, in the early days of technology, a number of visitors were present to 'observe and learn' laser surgery. A laser procedure will only run smoothly and without accident if the theatre is organised properly in consultation with the members of the operating team, which includes the surgeons, anaesthetist, nurses and technicians. Whenever possible, similar types of cases should be grouped together, so that time is not wasted in changing the configuration of the theatre or the type of laser (with different wavelengths) in the middle of a session. The following paragraphs may serve as a guideline for laser surgery of each ENT region.

7.1. Laryngeal surgery

The configuration is identical to that of conventional microsurgery: the laser device and the microscope are placed on either side of the surgeon (see Fig. 1 in Chapter 4). The laser must be conveniently placed so that the control panel remains in sight of the operating surgeon, who may wish to confirm the parameters being used. A trained nurse or technician is in charge of the control panel of the laser, as discussed elsewhere. Another nurse is present for assistance. Staff numbers are kept to a minimum in order to avoid accidents.

7.2. Anaesthesia for laryngeal laser surgery

This topic is discussed in detail in Chapter 6. From a surgical point of view, it is necessary to have optimal access to the laryngeal pathology. This is not always possible due to the presence of the endolaryngeal anaesthetic tube. In the authors' experience, high-frequency jet ventilation (HFJV) (Fig. 4) provides an excellent view of the operative field, since the anaesthetic can be maintained with a very narrow metal cannula (Medtronic, Maastricht, The Netherlands) placed in the posterior larynx, between the arytenoids. Both supraglottic and subglottic ventilation are possible, as required. The cannula can be fixed directly to the laryngoscope (Mayne *et al.*, 1991). HFJV is unsuitable for cases in which the laser may not be effective in controlling excessive bleeding, since the jet pressure sprays fine droplets of blood onto the lenses, soiling them and hampering the procedure. When using high power pulses, caution must be taken to protect the subglottis and trachea with a wet pledget held with a microforceps. The use of metallic material is particularly reassuring since it replaces any flammable material in the operative field (Shikowitz *et al.*, 1991).

7.3. Surgery in the oral cavity

For surgery in the oral cavity under general anaesthesia, the configuration is similar to that of conventional intraoral surgery. The surgeon is usually seated by the head of the patient. The microscope, if used, and the laser are placed on either side of the surgeon.

If the procedure takes place in an office setting, the patient is seated in a reclining chair so that he or she can be laid flat if felt unwell. Occasionally, it is more practical to have the patient lying flat, with the head flexed by 45°. It is essential that protective eyewear is worn also by the patient. Electrocautery should be available to control any excessive bleeding. The surgeon is seated on a stool in front of the

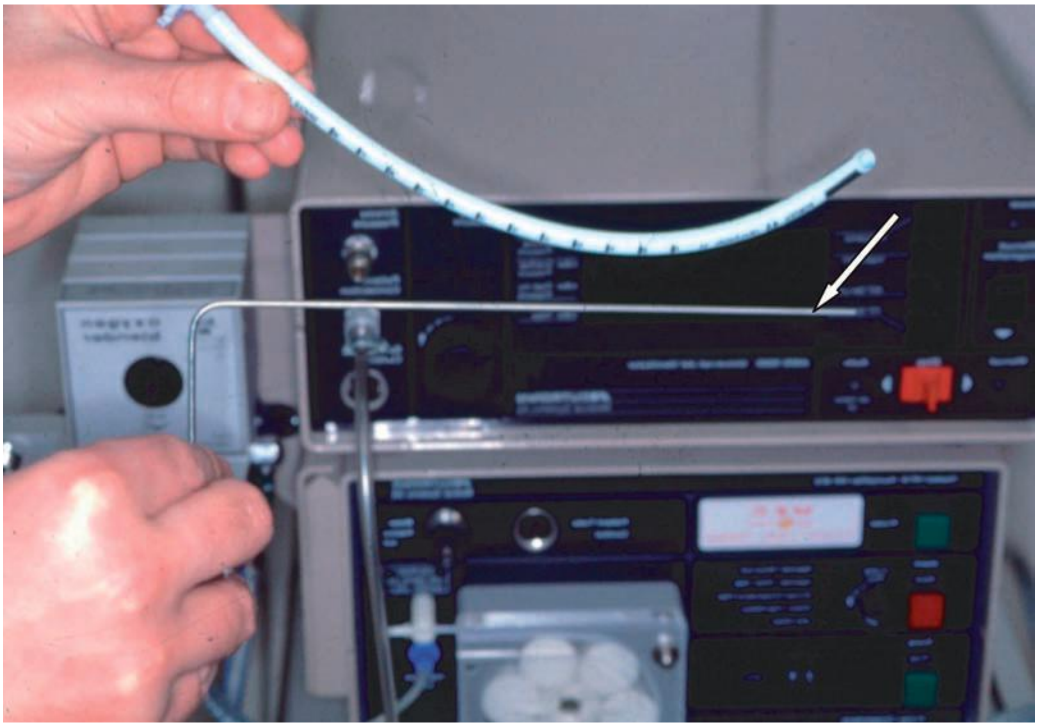

Fig. 4. High-frequency jet ventilation (in right hand) provides excellent unobstructed view for laryngeal surgery.

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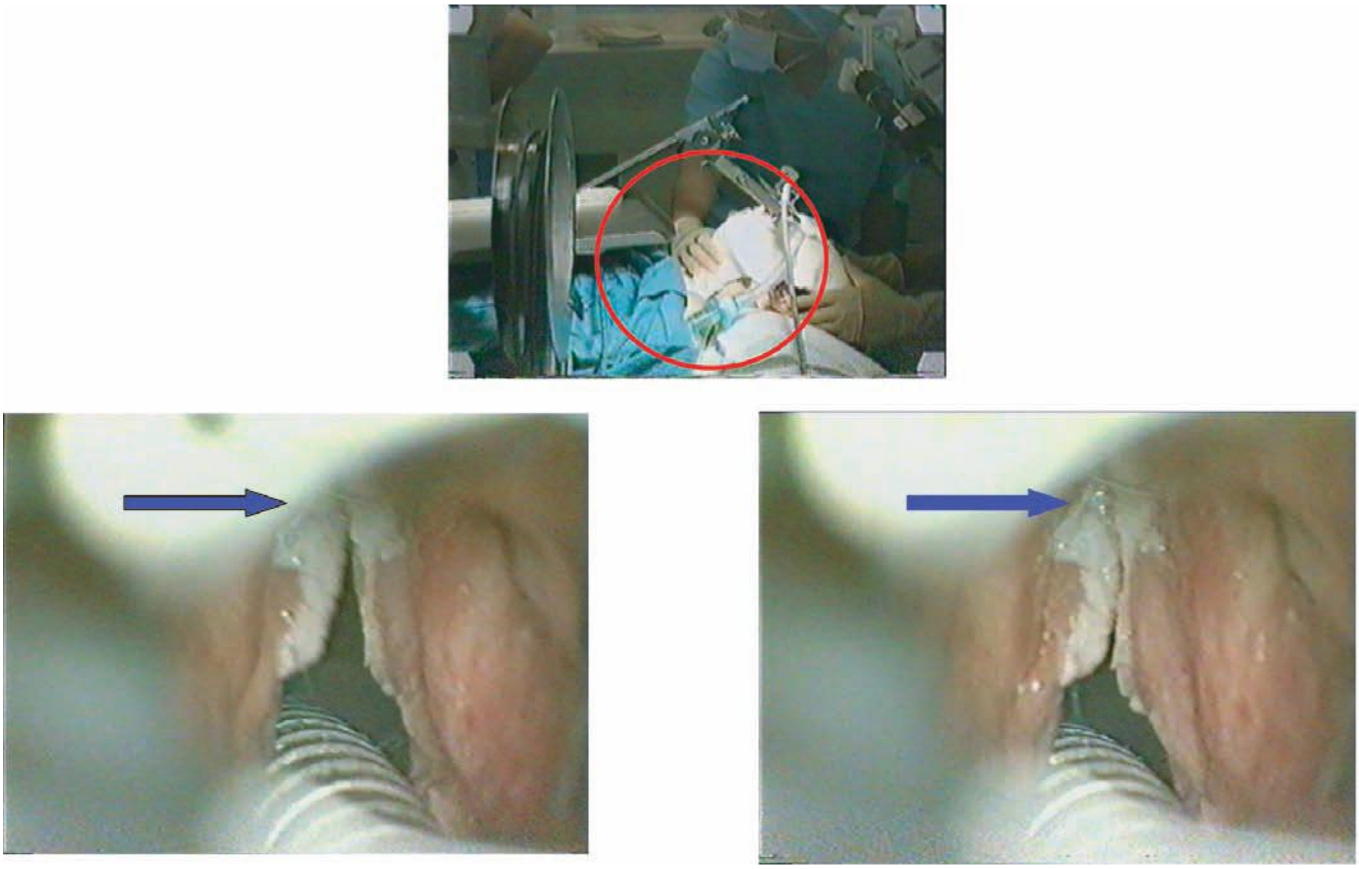

Fig. 5. Third-hand technique. Gentle pressure on the larynx improves endoscopic access.

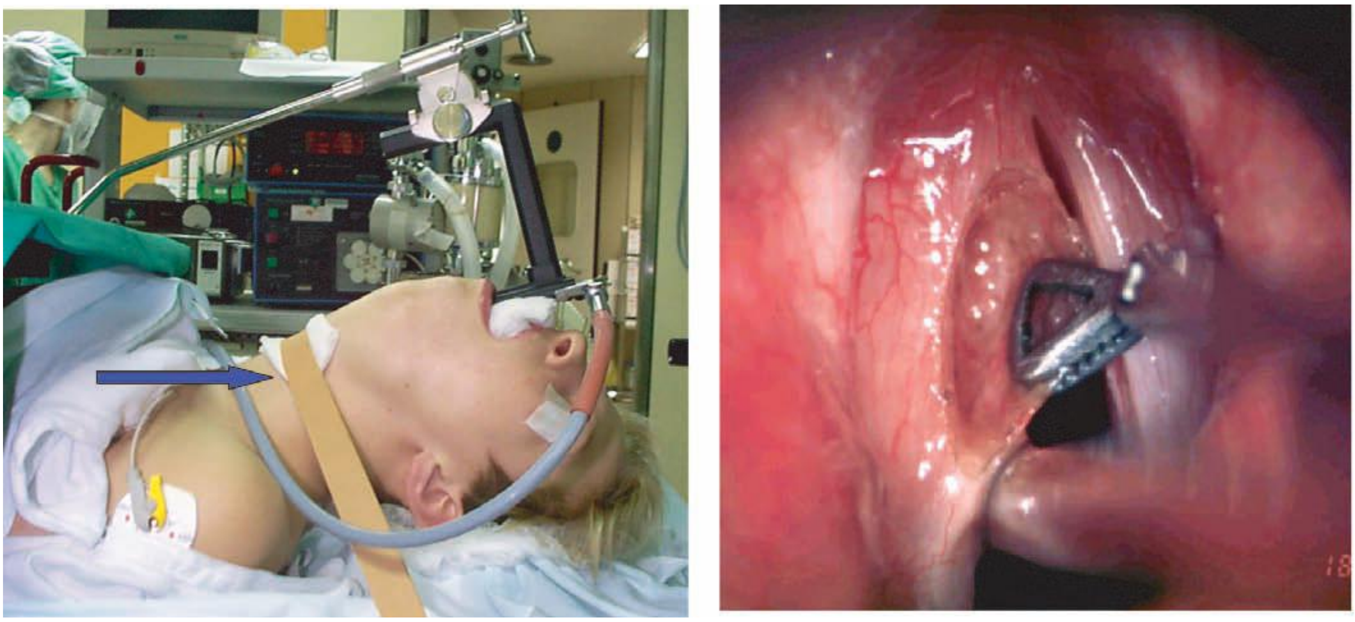

Fig. 6. Optimum endoscopic view is maintained by strapping the larynx.

patient. Both ventilation of the office and evacuation of any smoke at the operative site must be effective.

7.4. Endonasal surgery

Usually the patient is in a supine position. For local anaesthesia, the head and body are inclined. It is useful to place a smoke evacuator in the contralateral nasal cavity. Meticulous care must be taken to avoid inadvertent burning of the nares when using a free CO_2 laser beam. The laser is placed next to the surgeon.

7.5. Otological surgery

For middle ear surgery, the installation is conventional: the laser is connected to the microscope and placed next to the assisting surgeon. For office-based CO_2 laser-assisted tympanic membrane fenestration, the patient can remain in a seated or supine position. The laser is placed next to the surgeon. To feel secure, small children are allowed to remain seated in a parent's lap.

8. Surgical technique

Laser surgery differs from conventional surgery in a number of ways, as follows:

8.1. Lack of feedback

Surgery is undertaken with a free beam, or with the beam being transmitted via a fibre which is held in the near-contact position. Thus, unlike conventional scalpel or scissor procedures, there is no feedback to the surgeon's hand. Therefore, it is necessary to assess the surgical progress by direct palpation or by palpation with instruments.

8.2. Localisation of the target

When using a microscope, it is sometimes easier to move the patient's head in order to bring the target tissue into view.

8.3. Third-hand technique

If the target tissue is at the edge of the laryngoscope, gentle pressure on the laryngeal framework from outside brings the tissue into view within the laryngoscope (Fig. 5). During prolonged surgical procedures, the correct position of the larynx can be maintained by strapping sticking plaster to the neck (Fig. 6), or by the assistant maintaining gentle pressure if the procedure is short.

8.4. Non-target strikes

The face is covered with wet Gamgee in order to protect it and other flammable material (Fig. 7). Wet swabs are used to cover the areas in the immediate vicinity or, where possible, deep in the tissue. These swabs tend to dry out and may ignite so they should be periodically moistened or removed and replaced. Any metal instrument such as the suction cannula or forceps can also be used as a beam-stopper, thus protecting the non-target areas. However, sustained laser strikes on metallic beam stoppers should be avoided since the metal can get hot and will cause burns to nontarget tissue in the vicinity.

8.5. Evacuation of smoke

Smoke and vapour impair the surgical progress. They are also a health hazard, for both the patient and the theatre personnel. They must be evacuated in the vicinity of the operative field.

8.6. Depth of destruction

Vaporisation results in the immediate loss of tissue. However, there is also a delayed loss due to the irreversible thermal damage, which is dependent on a number of factors that have been extensively covered in Chapter 2.

8.7. Carbonisation

Charring results from inefficient vaporisation. Charred tissue absorbs the energy and heats up to high levels of temperature. The thermal energy causes flares, and it is also conducted deep into the tissue, thus resulting in much deeper thermal damage. Therefore, it is necessary to remove any charred tissue frequently with a wet swab or suction.

8.8. Stretching the tissue

As with conventional surgery, the effects of the laser are maximised when the tissues are stretched prior to vaporisation (Fig. 8).

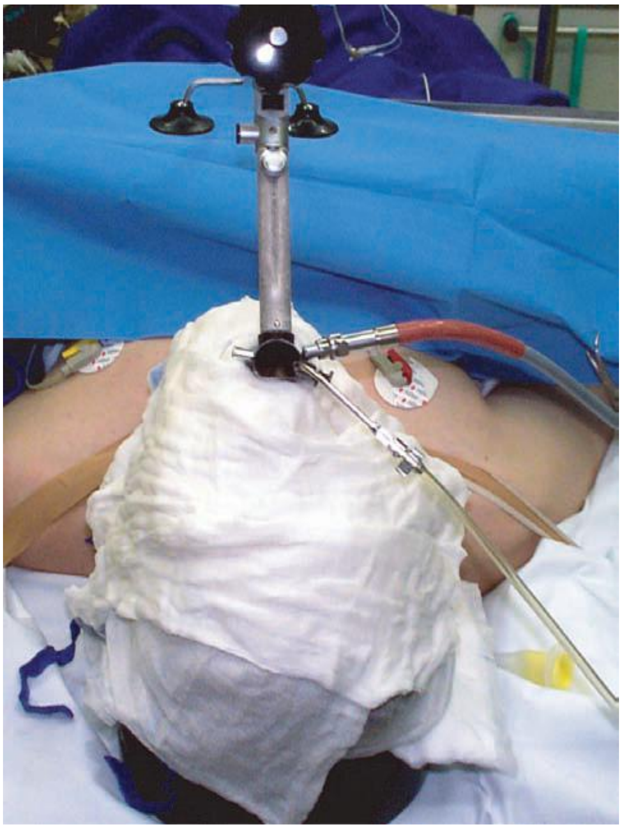

Fig. 7. Wet Gamgee protects face and flammable material from accidental laser strike.

8.9. Vaporisation or excision?

Vaporisation

Lasers can be used to ablate a given tissue by vaporising it, layer by layer. Thus, vaporisation is the prime, and most important effect in the clinical application of lasers. During the first exposure, as the temperature rises to 100°C, a layer of tissue vaporises. Continuing exposure will produce similar effect in the next layer of tissue. Thus, the layer of vaporisation is an ever-advancing layer, so long as the beam continues to strike the tissue. Therefore, increasing the power setting cannot result in a deeper cut. It will only result in an increase in the *rate* of vaporisation of the layers of tissue. If the speed of vaporisation is very high, due to high-energy settings, the beam will reach the underlying non-target tissue very quickly and it may be damaged inadvertently before the exposure is stopped. The analogy can be given of a car being driven at high speed in a deadend street. By the time the breaks are applied as it is approaching the end, it may be too late.

It is important to note that the subsequent layer of tissue following initial vaporisation is not of the same virginity with regard to its water content. This layer would contain tissue that has already suffered thermal damage. Therefore, having a lower water content, it will be less efficiently ‘ablated’. Increasing the energy beyond the vaporisation level will not increase the efficiency of vaporisation, but will merely result in the excess energy being conducted away, resulting in greater thermal damage to the tissues beyond the visible vaporisation.

As the junction between the pathological and the normal tissue is approached, the power setting should be lowered to avoid non-target strikes. It therefore follows that, when the mass of tissue being vaporised is small enough to be measured in millimetres (*e.g.*, a singer’s nodes), the vaporisation should be carried out at a much lower energy setting.

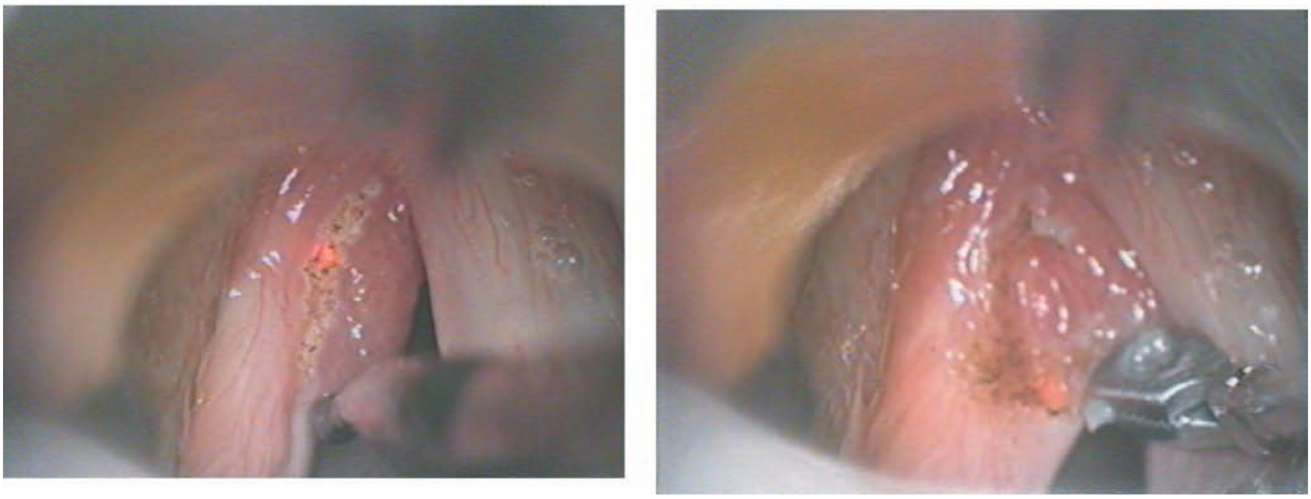

Fig. 8. Papilloma of left vocal cord. The tissue is stretched prior to excision by laser vaporisation.

Excision

Lasers can also be used to 'excise' a tissue, by vaporising a narrow band of tissue in the line of the incision, in order to develop a flap, deep enough to hold with a micro-forceps, and retracting it medially. This method allows dissection of the nodule from the normal underlying tissue and provides material for histological confirmation.

8.10. Intraoperative bleeding

Oozing should be controlled with wet swabs or swabs impregnated with a decongestant. Diathermy is necessary for large bleeders.

8.11. Wound toilet

At the end of the procedure, the wound should be wiped clean with a wet swab. Any debris and charring will thus be removed. If fresh bleeding starts, it should be controlled with decongestant swabs held briefly in position. Diathermy or further laser strikes may be necessary, but should be avoided to limit any delayed thermal damage. If a laser beam is used, it should be defocused so that the tissues are coagulated around the bleeding area.

8.12. Teamwork

In an operating theatre, the weakest link for a mishap to occur is untrained staff. However, when the procedure is undertaken by a trained team, the mishap will be due to complacency, pressure on the surgical time, tiredness, and so on. Accidents pertaining to laser usage are usually serious and extra care is necessary. Close liaison of the laser team with frequent consultations will ensure safe and effective surgery for the patient and will protect the staff from accidental injury. In cases of a mishap, the ultimate responsibility lies with the senior health care staff and the management.

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MCQ – 5. Theatre protocol and surgical technique

1. Operation theatre for laser surgery should have
    a. Laserproof and safe plumbing
    b. Dedicated smoke evacuator
    c. Warning signs at the entrance/exit doors
    d. All of the above

2. According to the American National Standard Institute's approval, warning sign at the entrance door of the operating room should indicate
    a. Wavelength of the laser being used
    b. Type of laser
    c. Caution: do not enter
    d. Laser power being used
    e. All of the above

3. It is necessary to check the alignment of CO_2 beam and aiming beam prior to surgery. This test is the job responsibility of
    a. Operating physician
    b. Laser safety officer (LSO)
    c. Laser technician (LT)
    d. Laser protection advisor (LPA)
    e. Varies according to practice laid down by each facility

4. Which of the following precautions are necessary to minimise fire hazard during laser surgery?
    a. Use oxygen concentration of 100%
    b. Wiping dry the flammable liquids (ethyl chloride, alcohol) prior to laser strikes
    c. Use paper drapes
    d. Use dry cotton pledgets, swabs
    e. Avoid or protect flammable material in the path of the beam and in the surrounding area

5. High frequency jet ventilation(HFJV) is not suitable when ---
    a. The lesion to be excised is situated in the anterior glottis
    b. Patient is thin built and short statured
    c. There is excessive bleeding during laser use
    d. HFJV is suitable in all of the above situations

6. During vaporisation of tissue with laser, increasing the power settings will result in
    a. Deeper cut
    b. Increase in rate of vaporisation
    c. Haemostasis
    d. Charring of tissue
    e. Increased collateral damage

Chapter 6

Anaesthesia for laser airway surgery

N. Puttick

1. Introduction

If pressed, my advice to an anaesthetist asked to provide a service for laser airway surgery *de novo*, would be simple: arrange a clinical attachment at an established centre in order to acquire the necessary skill and knowledge in a 'hands-on' manner, and remember not to let the surgeon set fire to the patient.

The purpose of providing an overview of anaesthesia for laser ENT surgery in a book primarily aimed at the surgical community is neither to produce a comprehensive review nor to instruct the novice laser anaesthetist in basic techniques. It is to summarise the current state of practice and to highlight common problems and present some of their solutions, with appropriate detail where required. Inevitably this relates to practice in the author's institution, and there are often alternative solutions. Experienced anaesthetists who regularly perform laser anaesthesia will use their individual skills and knowledge to ensure their patients' safety in a manner relevant to the surgical techniques used in their own clinical setting, often with different methods or emphasis. The acquisition of the relevant specific skill and knowledge base is as important to the *anaesthetist* as to the surgeon. The key point here is that a team approach is essential: furthermore, it must be recognised that all the experienced team members must be involved if safety and quality are to be delivered consistently.

The challenge of anaesthesia for laser airway surgery revolves around three major considerations: combustion, the airway, and anaesthetic risk. The causes and prevention of combustion will be considered first, as these will set the scene and help avoid repetition later. Management of the airway during induction and surgery is naturally of primary importance to the anaesthetist: this is often difficult due to pathology and the need to share the airway for surgical access. Finally, risk factors for anaesthesia and the related management of complications will be examined.

2. Combustion

Combustion requires a source of ignition, an atmosphere which supports combustion, and flammable material. Airway surgery with a laser has all these components.

2.1. Source of ignition

The thermal effects of the laser, which make it a suitable tool for surgical ablation, also make it a potent source of ignition. The laser provides a powerful source of energy concentrated in a very small area. The risk is greatest with a collimated beam such as a CO_2 laser, which remains in focus over a considerable distance from the exit aperture and thus retains its high power density. It can cause ignition both within and outside the surgi-

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cal field. A fibre-guided beam (*e.g.*, holmium: YAG or neodymium:YAG), on the other hand, diverges as it emerges from the tip of the fibre. Thus, its power density is only high at a short distance from the operating tip, where it may cause ignition. The energy decreases as the tip is moved away from the combustible substrate (tissue or tube). Risk of combustion is also less in lasers that operate in a pulsed mode, as heat can dissipate between bursts. It is worth noting that airway fires have also been reported with electrical diathermy (Baur and Butler, 1999).

2.2. Combustible material

Combustible tracheal tubes

The tracheal tube is the most critical element. Commonly used tubes such as red rubber, latex, and plastics such as PVC, are easily ignited in a typical anaesthetic gas mixture, burning with a blowtorch-like flame. Tubes made of silicone material are less easily ignited, but char and sustain a hot coal-like glow. These spectacular effects can readily be demonstrated under safety-controlled conditions (Figs. 1 and 2). It is therefore necessary either to protect the tube from the laser, or to use a tube made of a non-combustible material. Comparative studies of combustibility have been performed (Wolf and Simpson, 1988; Hunsaker, 1994), but these are of less interest since laser-safe tracheal tubes have become widely available.

Other combustible material

It is important to consider other combustible materials, and either to protect or eliminate them from the operative field. Dry swabs, pledgets, tapes, drapes, gum shields, nasogastric tubes, na-

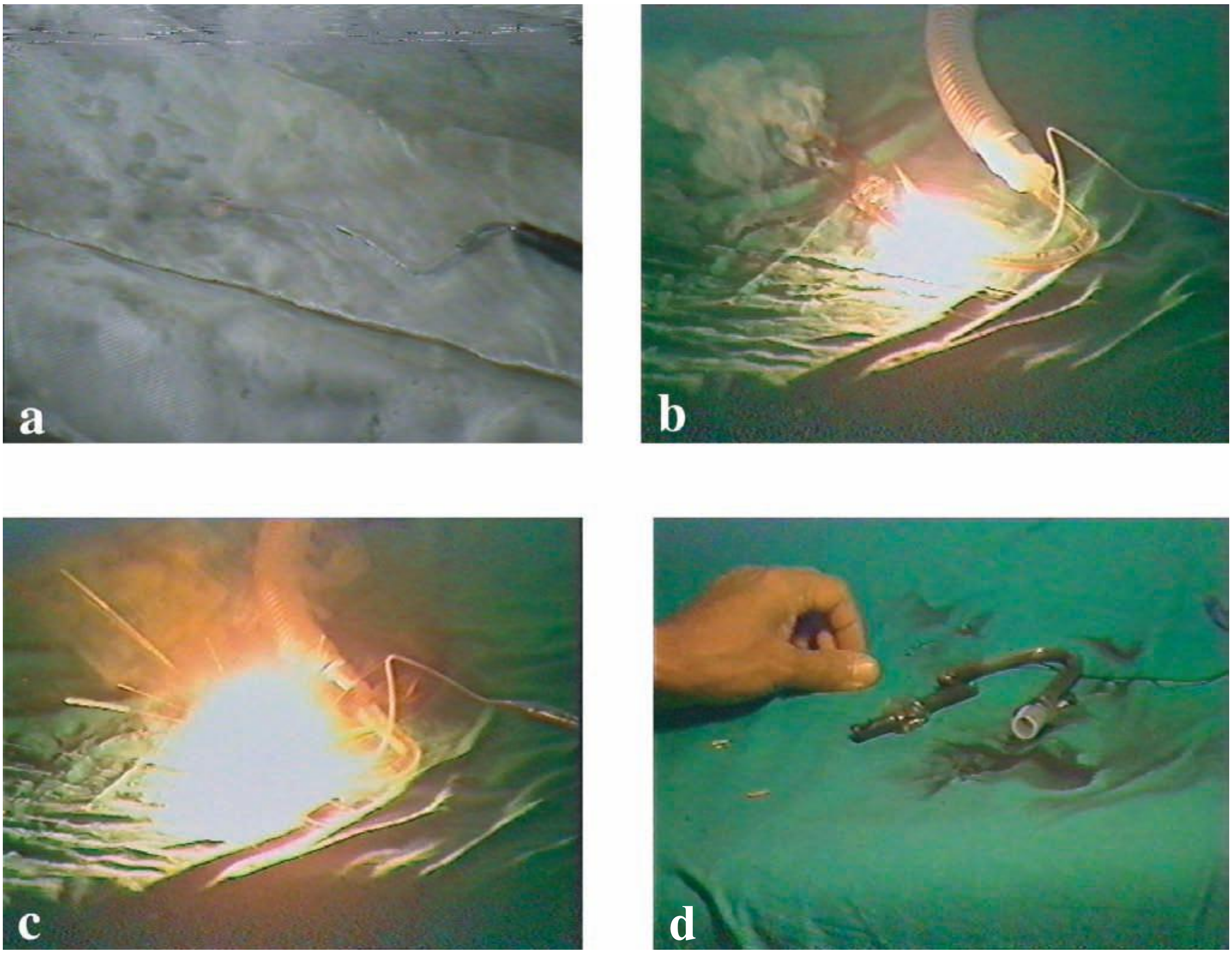

Fig. 1. A PVC tracheal anaesthetic tube ignites and burns with a blow-torch-like effect and is completely destroyed in under one second. a: PVC tracheal anaesthetic tube. b: Ignition. c. Conflagration. d. Melted residue (Courtesy V. Oswal).

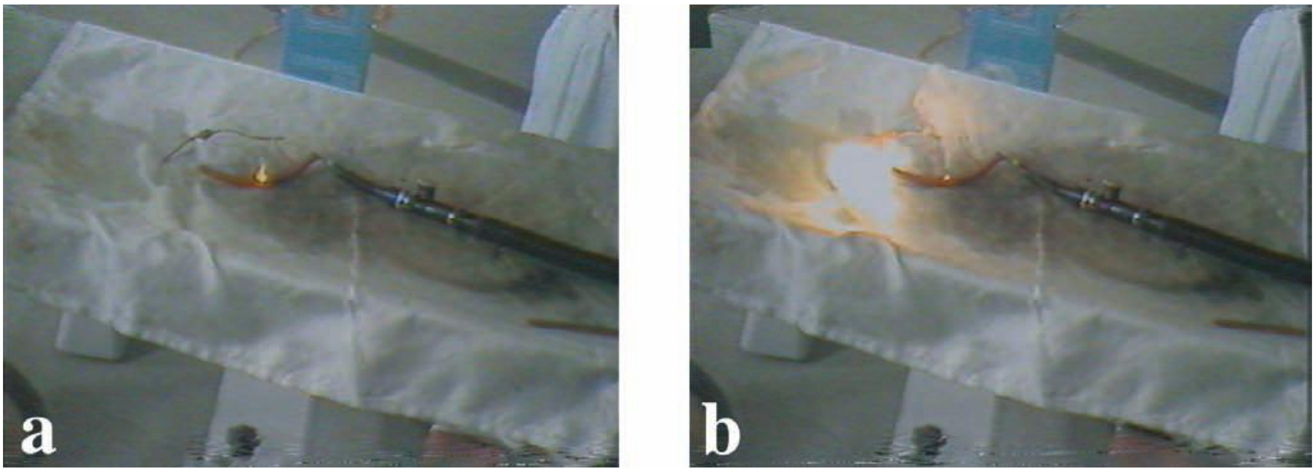

Fig. 2. Ignition of red rubber tracheal anaesthetic tube is somewhat slow, but once ignited, it also burns with a blow-torch like effect (Courtesy V. Oswal).

sopharyngeal airways, and non-metallic tracheostomy tubes are combustible (Wolf and Simpson, 1988). The target tissue itself can ignite and sustain a flame. Surgical 'prep' fluid containing alcohol (Fong *et al.*, 2000) or petroleum jelly used to protect the lips are flammable. Anaesthetic tubing and connections are almost universally made of combustible plastics and so need to be protected. The face of the patient is covered with wet material such as Gamgee (Chapter 5, Fig. 7). An aperture made in the Gamgee allows access to the operative site. A wet drape (over an impermeable layer) is placed on the patient's chest and neck area to cover anaesthetic connections. Water is fire retardant as well as being a heat sink, so all swabs and fabric should be wet. As they dry out, they should be either re-wetted or replaced.

2.3. Combustion-supporting atmosphere

Anaesthetic gas mixtures are, by convention, oxygen enriched. Oxygen, nitrous oxide and volatile anaesthetic agents support combustion, while inert gases, commonly nitrogen and helium, do not. With a tubeless or uncuffed-tube technique, the anaesthetic gases enter the surgical field, increasing the potential for combustion. Total intravenous anaesthesia (TIVA) with an air/oxygen mixture (*e.g.*, 25% O_2/75% N_2) reduces this risk. Tracheal intubation with a cuffed tube isolates the anaesthetic gases from the surgical field; with a leak-free system any anaesthetic gas mixture can be used.

3. Fire prevention in laser airway surgery

There are two general approaches to eliminating the risk of airway fire. The first relies on the use of an inherently laser-safe tracheal tube, or protecting the tube from laser strike. The second avoids the use of a tracheal tube altogether, in favour of a tubeless anaesthetic technique. No single particular technique is suitable for every case, and the choice will be very much dictated by a number of factors. These include the experience of the operating team, local availability of equipment, access to the operating site, and the type of pathology being treated.

The surgeon will naturally concentrate on the target lesion, rather than on the anaesthetic tube, yet must at all times be aware of its position. An unintentional direct or tangential strike can occur to the extent that ignition takes place. An indirect beam reflected from the surface of surgical instruments may also result in ignition of the tube. Even laser-proof tubes require care, since repeated laser strikes can raise the temperature of the tube, potentially causing thermal injury, and metal tube surfaces can reflect the laser beam causing ghost burns.

4. Intubation anaesthesia

4.1. Protection of standard tracheal tubes

Protection with wet swabs

CO_2 laser energy is highly absorbed by water.

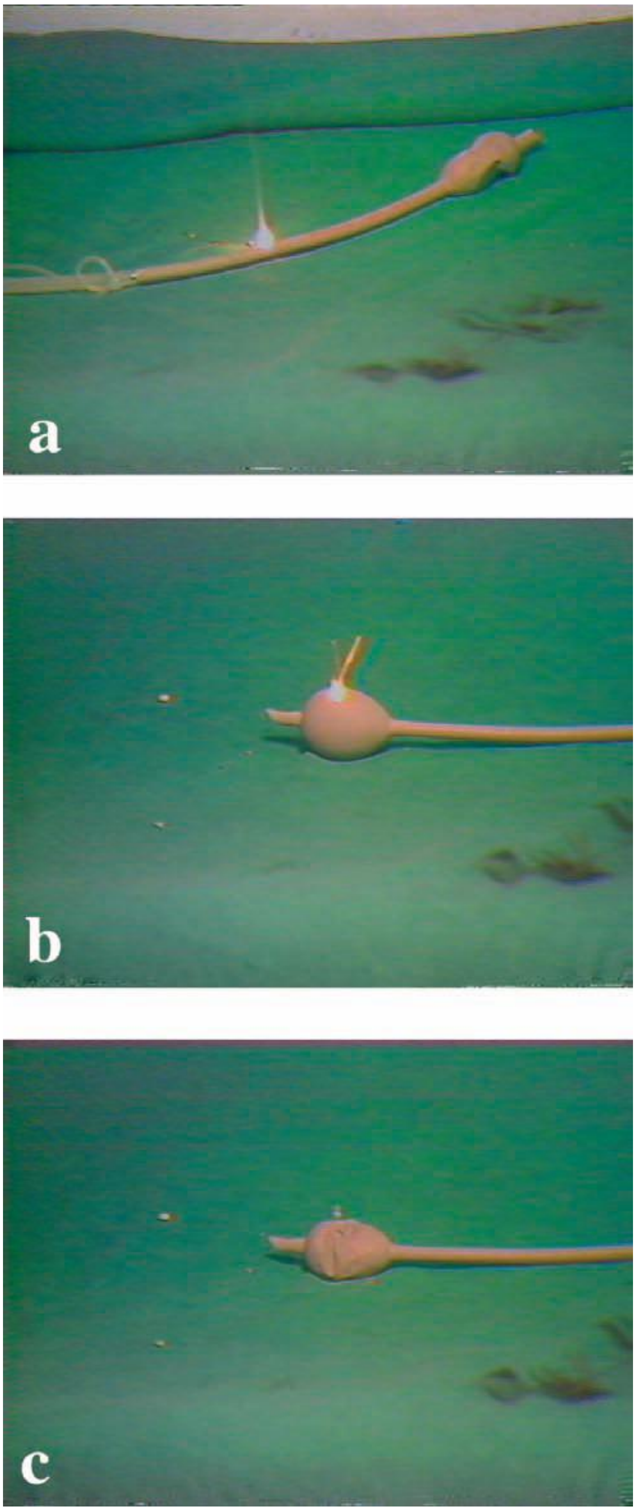

Fig. 3a, b, c. Xomed tracheal tube ignites, but fire is not sustained. The cuff remains vulnerable to ignition and fire, with loss of integrity of the anaesthetic circuit (Courtesy V. Oswal).

Wet swabs are placed on the exposed part of the tube, and these act as a heat sink by taking up the laser energy. While this method has been used successfully, it should be appreciated that the swabs dry out and need repeated wetting. Constant vigilance would be required to ensure that no part of the tube is exposed during surgery: this is outside the control of the anaesthetist and the technique is not to be recommended.

Protection of the tracheal tube cuff

The cuff of the tracheal tube remains vulnerable to direct or indirect laser strike (Fig. 3). If perforated, the integrity of the anaesthetic circuit is lost, and there is a possibility of combustion. Care must be taken to protect the cuff throughout surgery with water-saturated cotton pledgets or swabs (Sosis, 1995). As an added precaution, the cuff can be filled with physiological saline or water, and tinted with methylene blue. The release of dye signals that perforation has occurred and the risk of ignition is reduced since the water absorbs the laser energy.

Reflective wrapping of tracheal tubes

Combustible tubes have been protected by wrapping with metal foil, for example, self-adhesive aluminium tape (Sosis and Heller, 1988) or copper tape (Sosis and Dillon, 1990) (Fig. 4). However, the process is laborious and it is difficult to wrap consistently, even with practice. A foil-wrapped tube loses flexibility, and the surface is no longer smooth. The foil edge can cause trauma, particularly in nasal intubation, and portions of unprotected material can become exposed if the tube is flexed. The cuff cannot be wrapped and requires protection as described earlier. Accidental laser impact on the reflective foil does not cause tube ignition, but allows unintentional reflection of laser energy onto non-target tissue resulting in a secondary or 'ghost' burn. Product liability is a major concern since the user would be regarded as the manufacturer of a new device, and would be personally liable for injury resulting from any defects. Overall, such improvisation is a poor option and is not recommended.

Recently a new product intended specifically for wrapping combustible tubes has become available. Merocel Laser-Guard (Xomed) is a self-adhesive silver foil covered with sponge. Silver was chosen because it is a very good conductor of heat. The sponge must be kept wet with saline as it may ignite if too dry. Wrapping increases the outside diameter of the tube by approximately 2 mm. The author would be circumspect about the use of *any* wrapping, as the responsibility for

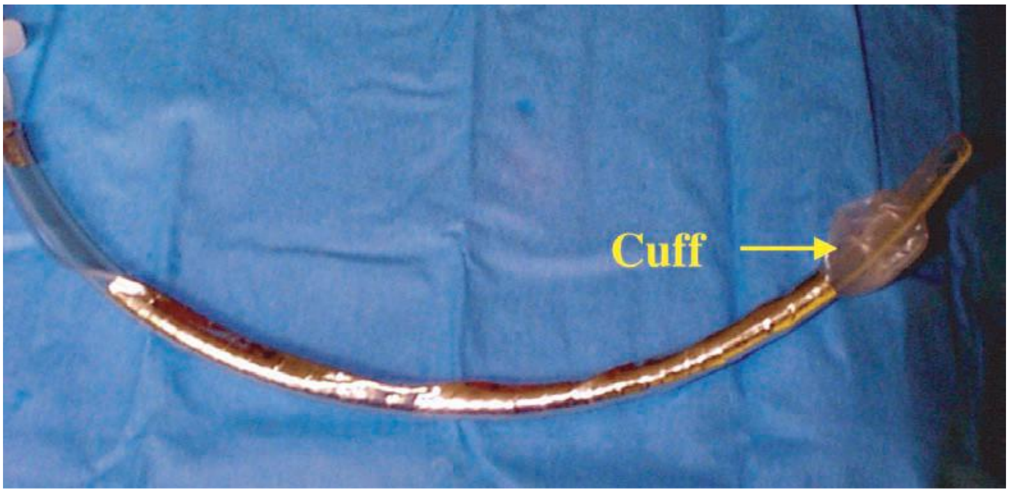

Fig. 4. Copper-foil wrapped PVC tracheal tube. Note: the cuff remains unprotected.

correct application and integrity during use would rest with the anaesthetist or their assistant.

Factory-wrapped tracheal tubes

Some manufacturers produce wrapped tubes, which are manufactured to a high standard and approved by regulatory bodies. These have common features of a reflective metallic foil under an absorptive layer, and provide good protection. However, the proximal and distal ends of the tube remain exposed, and should be protected. The Sheridan Laser-Trach™ is based on a red rubber tube, protected by a spiral wrap of adhesive copper foil, and overwrapped with fabric that has to be kept soaked with saline. The Xomed Laser-Shield II™ (Green *et al.*, 1992) is a silicone tube protected by aluminium foil under a Teflon covering, and uses a saline filled cuff pre-dyed with methylene blue. It is worth noting that the product information leaflets for both these tubes state that they may only be used with CO_2 or KTP lasers. It must be emphasised that, with any product, the manufacturer's documentation must be checked before use regarding suitability for the type of laser intended to be used. On the other hand, the Rusch Lasertubus (Fig. 5) is described by the manufacturer as being resistant to *all* types of medical lasers. It is made of soft white rubber, protected by a layer of silver foil and covered with a layer of Merocel, which should be wetted with saline. In addition, it has dual saline-filled cuffs, one inside the other.

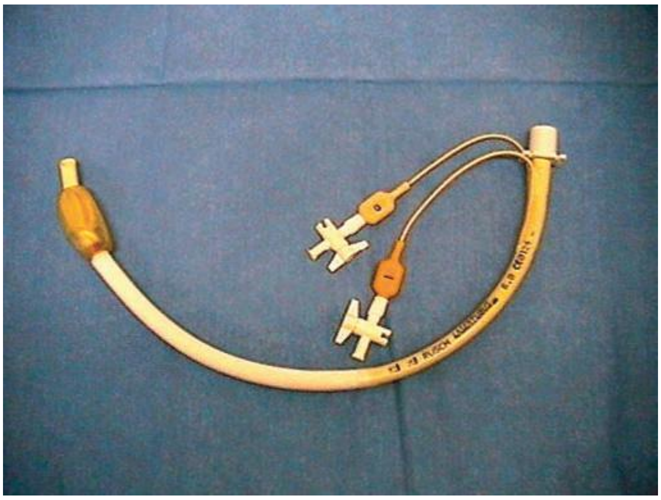

Fig. 5. Rusch Lasertubus, described by the manufacturers as being resistant to all medical lasers.

Silicone rubber tubes with metallic protection

When silicone rubber is heated, a coating of silicon dioxide is formed, which is relatively heat- and flame-resistant. It does ignite in the presence of oxygen, but does not sustain combustion. The maximum recommended oxygen concentration when using these tubes is 25% (Sosis, 1990). The Bivona Fome Cuf laser resistant silicone tube has an inner aluminium layer that resists laser penetration, and a foam-textured cuff that is wetted with saline and remains inflated after perforation. The Xomed Laser Shield tube was constructed of silicone that had a matt dark grey appearance, due to impregnation with aluminium powder. This tube could char and become very hot if repeatedly struck, and could also be ignited. The thinner

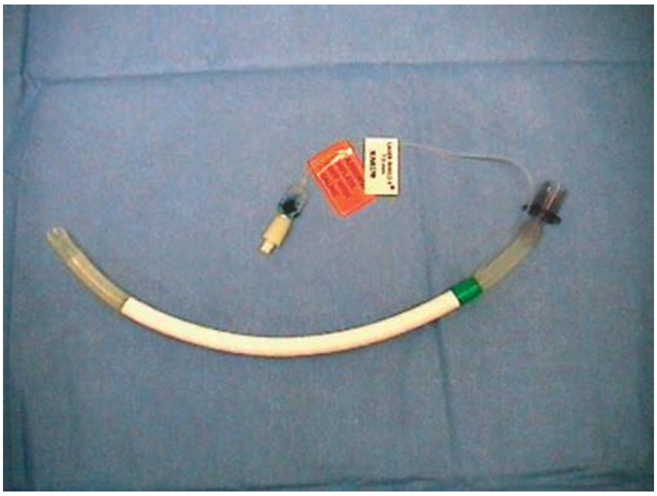

Fig. 6. Xomed Laser Shield II cuffed tracheal tube.

aluminised cuff was easily punctured. It is no longer commercially available, having been replaced by the Laser Shield II (Fig. 6).

4.2. All-metal tubes

Tracheal tubes constructed with a continuous outer metal surface would be expected to provide the gold standard in laser safety.

All-metal non-cuffed tubes

Norton and DeVos (1978) developed the first totally fireproof all metal construction tube, specially designed for laser-assisted surgery. A further development was the Oswal-Hunton flexometallic tube, developed at North Riding Infirmary, Middlesbrough, UK, and marketed commercially by Downs Medical (Hunton and Oswal, 1985; Fig. 7). These tubes have an appearance and construction similar to a 'swan-neck' desk lamp or the spiral metal covering of a shower hose, and are available in adult oral, adult nasal, and paediatric oral sizes. Having an all-stainless steel construction, they are totally non-combustible. As there is no cuff, an airway seal is obtained by placing wet square gauze pieces held by steel wire and packed in the subglottis. However, even with careful packing, leakage is inevitable, resulting in flooding of the operative field with anaesthetic gas, which can increase the risk of combustion of non-tube material. Unacceptable pollution of the operating theatre environment can occur unless a TIVA technique is used. Respiratory gas monitoring is made difficult, as expired gases are exhausted around the tube via the pharynx rather than into the expiratory limb of the anaesthetic breathing system. Spiral construction increases the thickness of the wall, resulting in a narrow bore for a given size, and thus a higher resistance to flow. The ridged internal surface results in turbulent gas flow, which further increases the resistance. A high flow, high-pressure anaesthetic ventilator system is therefore required. Mechanical flexibility is rather limited. Although no cord trauma has been recorded from the ridged spiral surface, care is needed at insertion and extubation. When used nasally, the nasal mucosa can be protected by a split rubber tube which is withdrawn after successful placement. These tubes

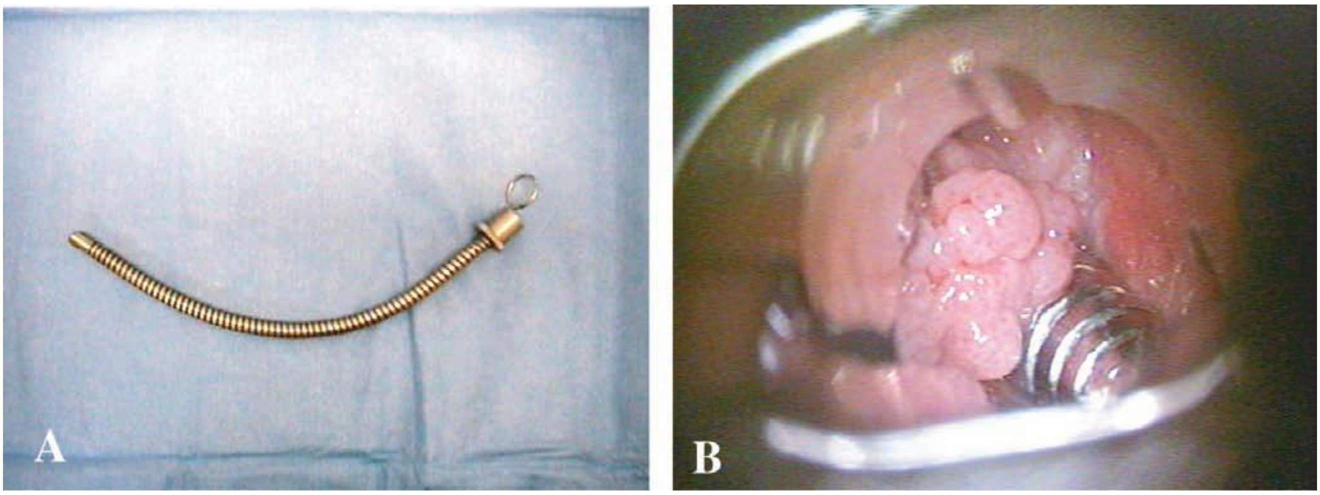

Fig. 7. A. Oswal-Hunton flexometallic tube. B. Its use in extensive papilloma of the larynx (Courtesy V. Oswal).

are durable and fully re-usable, and so very cost-effective, though difficult to clean internally.

Metal cuffed tubes

The conceptual successor to the Oswal-Hunton tube is the Mallinckrodt LaserFlex® (Fig. 8), which is approved for use with CO_2 and KTP lasers. It has a gas-tight stainless steel spiral construction (Fried *et al.*, 1991) which prevents laser penetration. Flexibility is good, and the outer surface of the spiral is relatively smooth. Its convex surface is claimed to defocus the laser beam and reduce the likelihood of ghost burns. It is available in adult and paediatric sizes. The adult tubes have two large, soft PVC cuffs, which can be filled with saline to achieve a seal. If the proximal cuff is accidentally punctured, the second, distal cuff maintains a seal. However, both tubes have an unprotected distal PVC tip and a rigid plastic proximal connector.

The design and construction of these tubes results in a relatively high resistance to gas flow. For a typical adult LaserFlex tube with an outside diameter of 7.9 mm, the internal bore is only 5.5 mm, and the tube is sufficiently long to allow nasal or oral use. Poiseuille's formula for laminar gas flow in a tube shows that resistance increases in direct proportion to length and in inverse proportion to the fourth power of the radius. A long, narrow tube will have a high resistance to flow. Moreover, the inner surface is ridged, promoting turbulent flow which further increases resistance. Taking all these factors into account, it is evident that resistance to gas flow and therefore inflation pressures will be high, which in practice requires adjustment of ventilator settings and alarms to compensate. The cuffs isolate the anaesthetic gas mixture from the operative field, allowing the use of any normal anaesthetic gas mixture or technique. Gas monitoring and ventilation are unaffected.

However, another problem is introduced as the two pilot tubes for filling the cuffs run *inside* the lumen. A fibreoptic intubating laryngoscope, which has a diameter of 4 mm, cannot be passed through it. This limitation may require some adaptability on the part of the anaesthetist faced with a difficult intubation. For example, the fibreoptic laryngoscope can be used to introduce a conventional PVC tracheal tube, and then a device such as a Cook airway exchange catheter used to change to the LaserFlex. The LaserFlex tubes are marketed for single use only, and are expensive. However, they are very safe and simple to use and, in the author's opinion, their many advantages justify their cost.

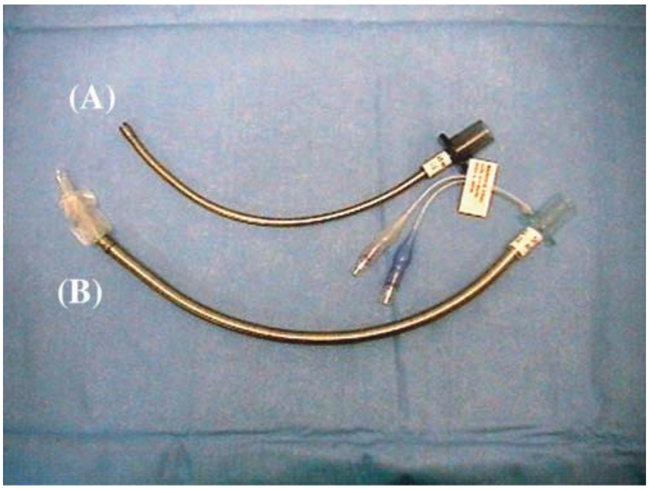

Fig. 8. Mallinckrodt LaserFlex tracheal tube. A. Mallinckrodt paediatric uncuffed tube. B. Mallinckrodt adult cuffed tube.

4.3. *Jet ventilation anaesthesia*

Jet ventilation is an alternative to tracheal tube anaesthesia. There are many devices and techniques, which have the common aim of providing good surgical access as there is no tracheal tube to obstruct the view. The general principle employed is the Venturi effect. A high pressure gas jet, usually oxygen or air, is directed into the airway or instrument and thereby entrains room air or anaesthetic gases to ventilate the patient's lungs.

Subglottic jet ventilation

Subglottic jet ventilation provides good surgical access. It can be accomplished with a percutaneously placed transtracheal or cricothyroid cannula. Alternatively, a transglottic jetting cannula can be used, examples of which include the Ben-Jet and Hunsaker cannulae.

There are a number of special considerations when subglottic ventilation is used. Expiration occurs through the patient's airway and not via the small lumen of the cannula. Therefore, it is essential to ensure that the airway is unobstructed throughout the procedure in order to avoid any risk of tracheal barotrauma or pneumothorax. Any pathology obstructing the upper airway therefore precludes the use of these techniques. Consideration must be given to the combustibility of the cannula material, whether it is visible in the surgical field, and if so, how to protect it without obstructing the airway. Monitoring of respiratory gases is difficult or impossible to achieve, as the end-tidal sample required cannot easily be obtained. Such monitoring is now generally considered mandatory, and so this limitation can pose a dilemma for the anaesthetist. Adequacy of ventilation can only be assessed indirectly by monitoring peripheral oxygen saturation (S_pO_2), and by visually observing chest expansion. Arterial blood gas analysis can be of use in prolonged procedures, but does not provide the necessary real-time information.

A jet ventilator is needed – this uses a high velocity gas jet delivered via a narrow-bore cannula to draw the ventilating gas into the trachea by the Venturi effect, and is used with TIVA and an air/oxygen gas mixture in order to avoid pollution. Jet ventilators can be manual, such as the well-known generic 'Sanders' injector', or automated, such as the Penlon Nuffield 200 with a jetting attachment in place of the standard patient valve. Automated devices are far more suitable for routine use.

Two specific transglottic devices have been described. The prototype was the Ben-Jet, which was a narrow bore cannula with a 'basket' at the distal end to centralise the cannula in the tracheal lumen. The Hunsaker Mon-Jet cannula (Sheridan) can be considered a development of this concept (Hunsaker, 1994). This is a 3-mm Teflon cannula, with a 1-mm channel to allow gas and pressure monitoring, and a centralising basket at the distal end. It has a wire passing through the lumen, which can be used to extract the device if transected by the laser. While it can be severed by the laser beam, the Teflon used will not sustain a flame even in 100% oxygen. User-constructed devices such as modified central venous catheters have been described, but such improvisation cannot be recommended due to performance and product liability considerations.

Jet ventilation via a laryngoscope or bronchoscope
In some instances, it is possible to use jet ventilation through the instrument used for surgical access. A metal jetting cannula can be fitted to, or incorporated in, an operating laryngoscope or bronchoscope. If an operating laryngoscope is being used, care must be taken to ensure that the aperture is well positioned over the glottis for efficient ventilation to be achieved. Normally a suspension system is used, and it is important to ensure that this rests on a rigid support above the patient's chest, rather than on the chest itself. Pressure exerted by the suspension system will effectively reduce the chest wall compliance and may severely restrict the tidal volume that can be delivered. Conversely, effective chest expansion may cause unacceptable movement of the laryngoscope. Jetting via a bronchoscope is less problematic, but carries a greater risk of barotrauma, owing to the better gas seal obtained with the instrument, particularly when only one bronchus is being visualised. As with subglottic jet ventilation techniques, the only measurements of lung ventilation available to the anaesthetist are S_pO_2 and visual monitoring of chest expansion.

High-frequency jet ventilation
High-frequency jet ventilation (HFJV), which requires a specialised ventilator, can be administered using a metal catheter specially designed for laser-assisted surgery (Chapter 5, Fig. 4). The catheter sits in the supraglottis, or may be advanced to the infraglottic region. Alternatively, it can be attached directly to the laryngoscope (Mayne *et al.*, 1991). This method allows a wide view of the larynx, and in contrast to a tracheal tube technique, provides a good view of the posterior larynx. HFJV is not advocated when a risk of bleeding exists: the jet pressure sprays fine blood droplets onto the microscope, quickly soiling the lenses and considerably hampering the procedure.

5. Intermittent apnoeic technique

When tracheal intubation is considered desirable, but surgical access is compromised by the tube itself (for example, lesions of the posterior commissure), a technique which alternates between intermittent positive pressure ventilation (IPPV) and apnoea can be used. After establishing stable anaesthesia with muscle relaxation, tracheal intubation, and 100% oxygen with TIVA, extubation and reintubation are performed under direct vision by the surgeon, but under the control of the anaesthetist. Because this method relies on monitoring the patient's oxygen saturation, it is restricted to brief, non-haemorrhagic, and intermittent surgical steps (Cohen *et al.*, 1988). Surgery is performed during one- to two-minute periods of apnoea, alternating with three- to four-minute periods of IPPV. Monitoring of end-tidal CO_2 is possible during periods of ventilation, but the most important parameter is peripheral oxygen saturation (S_pO_2), which should not be allowed to fall below 90%. Based on these parameters, the anaesthetist controls the duration of apnoea. It is important to appreciate that spontaneous desaturation occurs considerably faster in children than in adults.

A considerable degree of adaptability is required on the part of the anaesthetist, as extubation by the surgeon goes entirely against the grain of all one's training and instinct! However, this can be a very safe and flexible technique when employed by an experienced team. If strict laser discipline is observed, a non laser-safe tube such as PVC can be used for periods of ventilation, often to advantage.

6. Tubeless anaesthesia

Tubeless anaesthesia can be provided using a spontaneous respiration technique with TIVA, or by external cuirass ventilation.

Spontaneous respiration, tubeless anaesthesia with TIVA

It is possible to avoid tracheal intubation entirely by establishing general anaesthesia with TIVA and allowing the patient to breathe spontaneously. In addition, local anaesthesia of the larynx can be provided either by topical spray or by infiltration around the superior laryngeal nerves. An air/oxygen mixture is supplied via a nasopharyngeal airway or cannula, or via a sidearm of an operating laryngoscope. With practice and meticulous technique, this method can provide good operating conditions with little cord movement. It is particularly suitable for children with a small airway, who are difficult to manage with tracheal intubation, owing to obstruction of the surgical field.

External cuirass ventilation

The tracheal tube can also be eliminated from the surgical field by using a cuirass ventilator. The technique involves intermittent negative pressure being applied externally to the chest. The Hayek Oscillator is a negative pressure ventilator which is commercially available and has been used successfully to provide a tubeless field for laser airway surgery (Monks and Dilkes, 1995). Four sizes of cuirass are available: these are made of a clear plastic and are applied to the anterior chest wall. The ventilator operates as a high-frequency oscillator (HFO), which achieves a very efficient mass flow of gas, using much higher frequencies and smaller tidal volumes compared to conventional ventilation or even HFJV. TIVA is used with air/oxygen, and while muscle relaxants are not required to achieve good ventilation with HFO, they may be used to prevent movement at the surgical site. Owing to the relatively high cost and specialised nature of the equipment, this technique has not become widely used.

7. Laser plume and tracheal intubation

When a cuffed tube system is used, surgically generated smoke collects at the operative site, quickly obscuring the view unless localised suction is used. The smoke can easily be removed by using instruments which incorporate a suction channel in a side arm, or by a separate suction cannula. However, when a tubeless technique, jet ventilation, or IPPV with an uncuffed tube is used, the expiratory gas flow forces the smoke plume out of the airway and into the theatre environment. This may seem to offer the advantage of improved visibility, but the plume is difficult to scavenge satisfactorily even with high-flow suction equipment, and such laser smoke plumes are known to pose a hazard to health.

8. Access to airway and surgical site

Access to the airway must be shared between the anaesthetist and surgeon. Abnormal airway anatomy or pathology may well complicate access. The anaesthetist should be conversant with a wide range of techniques for management of the airway. Specialised equipment is necessary, from the simple gum-elastic bougie to advanced aids such as airway exchange catheters and the fibreoptic intubating laryngoscope. Naturally, the anaesthetist's assistant must also be familiar with the preparation and use of these devices. In the case of critical upper airway obstruction, the surgeon should be immediately available to perform rigid laryngoscopy or to create a surgical airway, should this be needed. The detailed anaesthetic management of a difficult airway is beyond the scope of this chapter, and indeed, in the UK, there is a specialist society devoted entirely to this topic. The acquisition of such anaesthetic expertise is a central issue in the development of a team approach.

Laser airway surgery can involve any part of the respiratory tract, including the nose, nasopharynx, oropharynx, supraglottis, glottis, subglottis, trachea, and bronchial tree, as well as tracheal stoma surgery. Each surgical site has its own requirements and constraints.

Nose and nasopharynx

Any oral tube can be used: if it is not in the laser field, it need not be laser-safe. However, it should be protected with a wet pack in the oropharynx, and the face protected by wet drapes or Gamgee.

Oropharynx

When a CO_2 laser hand piece is being used, the risk of ignition is high and a fully laser-safe tube, such as the LaserFlex, must be used, which can be placed either nasally or orally. However, when laser-assisted tonsillectomy or uvulopalatoplasty (LAUP) is being performed with a fibre-guided laser such as the holmium:YAG, the risk of ignition is greatly reduced as the energy density is concentrated at the fibre tip. In the author's institution, this surgery is routinely performed using a conventional preformed PVC oral tracheal tube, protected by a modified Boyle-Davis gag (unpublished data) (Fig. 9). The slot in the tongue blade is converted into a completely covered channel by the addition of a 1.5-mm thick strip of stainless steel silver-soldered to the upper surface of the blade. Our own engineers carried out this modification, and a full range of sizes is currently in use. Before surgery commences, the tracheal tube is secured in the midline and placed in the channel so that it lies between the tongue and the blade. When the gag is opened, the tube remains completely covered and therefore protected from the laser. Used in conjunction with a wet pack in the hypopharynx and wet Gamgee or drapes over any externally exposed parts or connections, this method affords total protection of the tube.

Larynx

One of the most successful applications of the surgical laser is in the management of laryngeal pathology. The CO_2 laser is the instrument of choice because of its shallow depth of penetration. As the CO_2 laser beam is collimated, it retains its energy density over a much greater distance, and the risk of ignition is high. The pathology may range from simple uncomplicated vocal cord nodules to tumour masses causing critical airway obstruction. Good communication with the surgical team is essential in order to ensure that the anaesthetist is forewarned of any potential intuba-

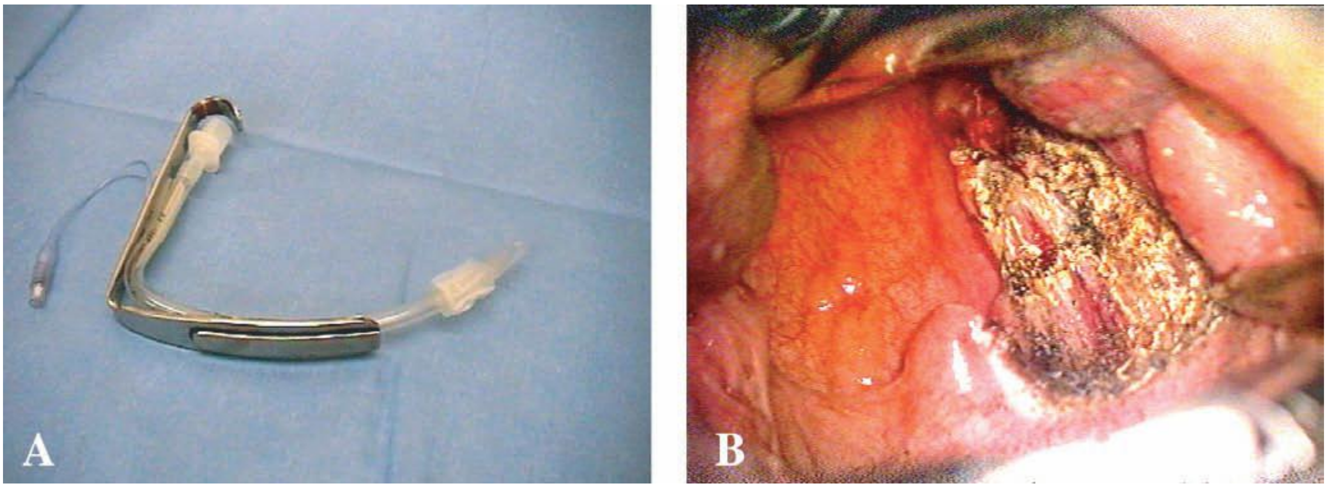

Fig. 9. A. Modified Boyle-Davis gag (N. Puttick). B. A groove in the metal blade provides complete protection to the PVC tracheal tube for laser tonsillectomy etc.

tion difficulty. It is often useful for the anaesthetist to visualise the lesion preoperatively, using a nasendoscope. Photographs or line drawings are also very helpful.

Routine laser surgery to small, non-obstructing lesions of the larynx is most easily carried out with a laser-safe tube, such as the LaserFlex. The anaesthetist can quickly establish the airway and a conventional anaesthetic technique can be used. The surgeon is able to use the CO_2 laser without the risk of fire. Wet swabs placed beyond the target will protect the cuff (Chapter 7, Fig. 4). The additional cost is minimal in the overall context of the case. If access to the posterior larynx is difficult with the tube in place, and cannot be overcome by positioning, the intermittent apnoeic technique or a tubeless technique can be used. In some situations, the tubeless technique may the method of choice, for example, in a child with laryngeal papillomatosis and a small glottic aperture.

The greatest skill is required in cases where debulking of an acutely obstructing malignant tumour of the larynx has been planned as an alternative to emergency tracheostomy. These patients have a critically compromised airway and access must be established promptly, without worsening the obstruction. The need for a team approach is nowhere greater than in these obstructed cases. Difficulty with laryngoscopy and intubation is to be expected, and an experienced anaesthetist is essential. The surgeon must be immediately available to create a surgical airway if needed. In many instances, the smallest practicable LaserFlex tube, or a laser-safe alternative, is a good choice. Should the presence of the tube restrict access, the intermittent apnoeic technique, with TIVA, can be used. Jet ventilation via the operating laryngoscope is also possible, but great care is necessary when the upper airway is even partially obstructed. Application of jet ventilation above the glottis for tumour surgery can force tissue, debris, and smoke into the distal airways. Subglottic jet ventilation may be safe if the upper airway is reasonably patent, but the entrainment of air by the Venturi effect, which provides the bulk of the gas flow, may also carry debris into the bronchial tree.

Tracheostomy

In patients with an existing tracheostomy, laser surgery may be necessary in the larynx or trachea above the stoma, or even within the stoma itself. For laser surgery above the level of the stoma, if the surgical field is sufficiently distant, a conventional plastic tracheostomy tube, protected by wet subglottic swabs, could be used. Packing of the subglottic space can be accomplished either from above, by inserting wet ribbon gauze, or directly through the tracheal stoma, by displacing the tube caudally.

For surgery within the stoma, for example, to correct a stenosis or excise a recurrent tumour, a laser-safe tube can be placed via the tracheostomy. Care is necessary to ensure that it is not inserted too far, in order to avoid inadvertent intubation of one bronchus. However, the presence of a tube often completely prevents surgical access to the lesion. A better alternative is to use the intermittent apnoeic technique, which then allows completely unobstructed surgical access. Any conventional plastic tracheostomy or laryngectomy tube can be used, and of course tube insertion and removal are very straightforward for the surgeon. The tubeless, spontaneously breathing technique has also been used, with both general and local anaesthesia.

Bronchoscopy

Endobronchial laser surgery is technically difficult, especially for more distant lesions, or where there is marked airway obstruction by tumour. Surgery is usually palliative, and the patient may be terminally ill, with compromised lower airway patency, and concomitant cardiorespiratory disease. The tumour itself may be on the carina, extending in both bronchial openings. The patient may have undergone previous pneumonectomy and present with a recurrence in the only functioning bronchus.

There are also many potential surgical problems that can create difficulty for the anaesthetist, including tracheal penetration, tracheal collapse, tumour herniation, and bleeding, to name but a few. Endobronchial laser surgery is strictly only for experienced teams.

A rigid operating bronchoscope is used, with a fitting to couple the laser micromanipulator to the proximal end. There are two methods of providing ventilation, dependent upon the design of the bronchoscope. Jet ventilation can be applied by using either a jetting cannula as an attachment or via a dedicated side arm. An alternative is the Wolf system, which is closed at the viewing end by a transparent Mylar film membrane. The Mylar film provides a gas seal which enables IPPV with a conventional ventilator to be used. However, the membrane is easily punctured by repeated strikes of the CO_2 laser beam and requires regular replacement every few minutes if the system is to remain gas-tight.

When operating in one or other main stem bronchus, only one lung can be ventilated, which poses considerable additional anaesthetic problems. High inflation pressures and relative hypoxia are inevitable. Extraction of laser plume smoke can be problematic, as can anaesthetic gas pollution, though this can be eliminated by the use of TIVA.

9. Risk factors for anaesthesia

9.1. The patient

The least challenging patients for the anaesthetist involved in laser airway surgery are fit young adults undergoing surgery to minor vocal cord lesions. Some patients, for example, those with recurrent respiratory papillomatosis, will require multiple repeat anaesthetics, which do not usually present a problem with modern agents. However, many patients with vocal cord lesions are older and have co-existing respiratory disease, often smoking-related, and other co-morbid conditions related to age, such as ischaemic heart disease. The brief duration of laser surgery and the relatively rapid, uncomplicated recovery period are positive features in the management of this group. Much laser surgery, of course, is for cancer, and is often palliative. In this group, the anaesthetist must be prepared to accept patients who are elderly, often with multiple pathology, poor nutrition, and metabolic disorders, with little prospect of improvement before anaesthesia and surgery. Critical airway obstruction may be encountered, and difficult anatomy may result from tumour mass or post-radiotherapy changes. Consequently, these patients form a high-risk group and this must be accepted by all parties: the clinicians, the patient, and the patients' relatives. Good communication is of the greatest importance. Once the risk is accepted, the potential benefit is great, as good palliation is often achieved, even with apparently crude techniques such as debulking of a supraglottic tumour. Major procedures are surprisingly well tolerated, as they can be carried out quickly, with less blood loss, and more rapid recovery. As relief of critical airway obstruction may be an essential prerequisite to definitive surgery, consideration should be given as to how best to achieve this. For example, a relatively common clinical dilemma is whether to perform an elective tracheostomy before proceeding, or to intubate and then de-bulk a tumour and assess the likely airway patency after surgery but before extubation. With careful decision-making, a tracheostomy may be avoided. Conversely, after surgery the airway patency may become marginal, and an appropriate decision to proceed to tracheostomy should be made in a timely manner.

Small children requiring laser airway surgery, for example, for papillomatosis or laryngeal anomalies, can pose particular problems. They have their own special paediatric anaesthetic and perioperative requirements, and frequently pose great technical challenges in terms of airway management. Laser-safe tubes in small paediatric sizes are readily obtainable. The uncuffed LaserFlex, for example, is available with an inside diameter of as little as 3 mm. However, the relatively thick wall imposes a compromise between a restricted lumen size and a relatively large outside diameter. Resistance to gas flow is high and an appropriate tube may completely obstruct surgical access. As discussed earlier, tubeless or intermittent apnoeic techniques may be more appropriate. The child and its parents may be very anxious and distressed by the surgical condition. Such patients should be managed only by a practitioner skilled in both the sub-speciality areas of laser and paediatric anaesthesia, and within the context of a similarly skilled operating team.

9.2. Anaesthesia problems intrinsic to laser airway surgery

Most of these have already been covered in the preceding sections. Particular problems include difficult airway or intubation, and shared access to the airway. The anaesthetist may have to use small and unfamiliar tracheal tubes, with high resistance, high ventilatory pressures, gas leaks, pollution, and difficulties with gas monitoring. Physical access to the patient may be restricted due to surgical equipment, microscope, video, drapes, and all the impedimenta of a laser theatre. In addition, there are visual restrictions caused by the necessity for laser-safe eye protection.

9.3. Anaesthesia complications arising from laser use

After any instrumentation of the upper airway, laryngospasm is common, and this applies following laser surgery. To reduce the incidence of laryngospasm, debris should be carefully wiped clear of the larynx, and topical 4% or 10% lidocaine spray used. Humidification of the oxygen routinely delivered in the recovery period is beneficial. In case of mild postoperative respiratory distress, the patient should be placed in the sitting position. This will reduce respiratory effort, as in any patient with a compromised airway. If there are signs or symptoms of airway obstruction, this can be caused by bronchospasm, oedema due to prolonged surgery and instrumentation, retained secretions, or the presence of loose tissue, debris, or blood. In the case of tracheobronchial surgery, the possibility of tracheal ring collapse due to laser damage, tumour herniation, and pneumothorax (which may be of delayed onset) should be considered. An early chest X-ray is advisable. Diagnostic or therapeutic bronchoscopy should be immediately available if indicated.

Admission to a high dependency area (HDA) should be available whenever needed, and so represents a minimum standard for postoperative care. The HDA should have skilled nursing and physiotherapy staff available, and be equipped with oxygen, suction, and effective humidification. Patient monitoring should include ECG, noninvasive blood pressure measurement, and pulse oximetry. Neonatal and paediatric laser surgery requires pre-planned admission to a suitable paediatric HDA or intensive care (PICU) in a specialist centre.

9.4. Airway fires

An airway fire is an iatrogenic disaster with high mortality. In the author's view, injury and damage resulting from fire would be difficult to defend in court, as it could be viewed as both foreseeable and preventable. Primary prevention by a meticulous technique is all-important. Specific drills have been advocated to minimise injury, for example, clamping the tube or quenching the fire with water or inert gas, but these are not likely to be effective. The author's protocol is based on the simplest, quickest, and most instinctive response:

- remove all the burning material immediately
- re-intubate and ventilate with high inspired oxygen

Urgent ICU admission should be arranged. The intensive care management is similar to that of severe smoke or flame inhalation, with full supportive therapy, including IPPV, bronchoscopy, lavage, and antibiotics. Early onset of pulmonary failure and adult respiratory distress syndrome (ARDS) is likely, with poor prognosis. If the patient survives, the subsequent course will be complicated by the extent of the thermal injury to the trachea. Peer-group discussion and medicolegal advice will be necessary and should be sought early, and a full discussion held with the patient's relatives. Primary prevention of airway fires depends not only on the correct choice of materials and techniques, but also on the rigorous application of laser discipline. The higher cost of the necessary skilled personnel, anaesthesia equipment and consumables must be accepted within the overall economic context of a laser surgery service: this is not the place to attempt to make cost savings.

10. Conclusions

In summary, anaesthesia for laser airway surgery requires detailed knowledge of, and skills in, airway management and the availability of specialised equipment and disposables. The airway is shared between surgeon and anaesthetist, who must each appreciate the nature and consequences of the other's interventions. There is high surgical co-morbidity in the patient population, which can include all age groups. Laser discipline and training is paramount, and the development of a team approach is essential. Surgery should only go ahead with an appropriately experienced anaesthetist, who knows and understands the surgeons and their practice. Anaesthesia for laser airway surgery is most definitely not for the novice or the uninitiated.

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MCQ – 6. Anaesthesia for laser airway surgery

1. Anaesthesia for laser airway surgery requires specific expertise because of which of the following reasons?
    a. There is a potential for airway fire
    b. Laser is a source of ignition
    c. Familiarity with several techniques is necessary
    d. Anaesthetic gases support combustion
    e. All of the above

2. The potential for airway fire caused by laser exists because of which of the following reasons?
    a. Laser is used at a high power density to remove bulky tissue
    b. Laser is used in continuous exposure mode
    c. The surgical field contains flammable material
    d. It is usual practice to administer high concentration of oxygen during airway surgery
    e. Nitrous oxide supports combustion at high temperature

3. The risk of airway fire can be minimised by which of the following techniques?
    a. Tubeless anaesthetic technique
    b. Non-reflective coating for instruments
    c. Reducing concentration of oxygen in the anaesthetic mixture
    d. Using laser-safe tube
    e. All of the above

4. Which of the following statements are TRUE regarding the use of endotracheal tubes in supraglottic laser surgery
    a. Cuff is not vulnerable and does not require protection
    b. A wet swab placed in the subglottic area provides adequate protection since it does not dry out even in prolonged procedure in supraglottis
    c. Unprotected cuff can ignite due to reflected beam
    d. Unprotected cuff can ignite due to impact from hot char particles
    e. Careful aiming on target tissue with He-Ne beam avoids direct laser strike on the cuff

5. All metal construction tubes such as Norton, or Oswal-Hunton flexo-metallic tube are truly fire proof tubes. Which of the following are the drawbacks of the above tubes?
    a. They do not have cuff
    b. They are not entirely non-traumatic
    c. They are for single use and therefore cost prohibitive
    d. They cannot be adequately sterilised
    e. Prolonged repeated use results in wear and tear

6. Which of the following is a drawback of the Mallinckrodt LaserFlex anaesthetic tube for laser anaesthesia?
    a. It will ignite at high power density setting
    b. It will ignite from reflected laser beam
    c. It will ignite if high concentration of oxygen is used
    d. It will ignite if used with CO_2 laser
    e. It is marketed as single use and thus cost prohibitive, but its advantages justify its use

7. Which of the following options are TRUE regarding subglottic jet ventilation
    a. Provides an excellent view of the operating field
    b. It is completely safe even in obstructed cases

   c. Results in difficulty in monitoring expiratory gases
   d. Used with TIVA and an air/oxygen gas mixture in order to avoid pollution
   e. The Hunsaker Mon-Jet cannula ignites but does not sustain fire even in 100% oxygen

8. Which of the following options are TRUE regarding laser surgery on the posterior larynx
   a. Tubeless anaesthesia provides excellent unobstructed operating field
   b. High Frequency Jet Ventilation is the method of choice
   c. Tracheal tube provides a superior control
   d. An intermittent apnoeic technique is ideal
   e. Initial tracheostomy to intubate through the stoma is advisable

9. Which of the following options are TRUE regarding intermittent apnoeic technique
   a. Is very useful in prolonged laser procedure
   b. A non-laser safe tube such as PVC can be used
   c. Monitoring of peripheral oxygen saturation (SpO2)is the most important adjunct
   d. It is a useful technique to complete the end stages of surgery in the posterior larynx where the presence of tracheal tube completely obstructs the surgical field.

10. Which of the following options should be undertaken in the event of a surgical fire
   a. Remove all the burning material immediately
   b. Re-intubate and secure the airway again
   c. Seek ITU admission
   d. Inform patient's next of kin
   e. Seek peer-group support in the management of the patient
   f. All of the above

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Chapter 7

Transoral laser laryngeal surgery

V. Oswal and M. Remacle

1. Introduction

Endoscopic surgery for laryngeal lesions began in 1939, when Chevalier Jackson used a tubular scope and punch biopsy forceps to remove epiglottic lesion. The 1950s saw the introduction of the operating microscope which provided much needed precision. Suspension micro-laryngoscopy in the 1960s freed surgeons' both hands for surgery. CO_2 laser complemented cold instrumentation in the 1970s, making endoscopic surgery almost bloodless, and therefore, much more precise. The 1990s saw the extension of endoscopic excisions to treat early cancers of larynx. Cost considerations in the first decade of the twenty-first century, along with technical advances in distal chip flexible endoscope and 3-D imaging, resulted in migration of the endoscopic laser surgery from the operating theatre to the office-based set up (Chapter 57).

2. Advantages of transoral laser laryngeal surgery (TLLS)

There are a number of advantages offered by transoral endoscopic approach with the CO_2 laser:

- The operating site is almost bloodless, thus providing an unobstructed view of the target tissue for its precise removal.
- There is minimum charring; the histopathological confirmation of clear margins is easier and more accurate.
- Bloodless field and lack of charring allows removal of diseased or dysfunction tissue layer by layer, thus delineating the interface between pathological tissue and the normal tissue most accurately. The preservation of function is thus maximised.
- Since there is virtually no postoperative oedema, there is no need for tracheostomy even after extensive excisions required for malignant lesions.
- The operative time and hospitalisation is shorter.
- Return to daily activity and work is quicker.
- Functional preservation of voice is greater with precision surgery; likewise, there is an earlier return of swallowing.
- Cosmetically, there is no skin incision on the neck.
- There is virtually no incidence of pharyngo-cutaneous fistula.

3. Disadvantages of TLLS

There are, however, certain disadvantages:

- The equipment requires a large capital outlay.
- Single use specification of fibres and hollow wave guides add significantly to the revenue costs.
- Specialised training in laser surgery is necessary to use the laser effectively and safely.
- The upper airway is shared by both the anaesthetist and the surgeon, who must appreciate each other's needs and priorities. There is always a potential to a surgical fire.
- The support staff in the operating department also needs to have adequate knowledge of the technology.
- A second procedure is required if neck dissection is in the overall management protocol.

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- Subglottic extension of the pathology cannot be approached transorally with a free-beam CO_2 laser. A fibre transmissible wavelength, such as the KTP 532 or the diode, is necessary for the management of lesions at this subsite. Recently, hollow wave guides have become available for the CO_2 wavelength, and their performance is promising (Chapter 59).

4. Pre-requisites for TLLS

- Adequate exposure of both the pathological tissue and the normal surrounding tissue is always necessary to achieve removal of diseased tissue and preservation of normal tissue for optimum function preservation. Bivalve laryngoscopes provide an excellent view of most of the larynx. The upper blade is placed in the vallecula and the lower blade butts against the endotracheal tube or the tissues of the posterior larynx, if the tubeless anaesthetic technique is used. The laryngoscope is repositioned as the surgery progresses, so that an optimal exposure is maintained at all times.
- In cases of bulky tumours, it is necessary to remove the tumour piecemeal and readjust the scope to re-orientate.

5. Contra-indications for transoral approach

- If adequate exposure of the lesion cannot be obtained for any reason, *e.g.*, cervical arthritis, short neck, long neck, full denture, the transoral approach may not ensure complete removal of pathological tissue, and/or preserve normal tissue.
- Some surgery for extensive cancer can last over a couple of hours. The patient's general condition must be fit for such prolonged surgery.
- Lack of an experienced team: during out-of-office hours, holidays, weekends, the usual experienced team may not be available. The use of lasers for obstruction conditions, such as obstructing malignant tumours may prove to be a liability. Under such situations, conventional measure is a safer option.

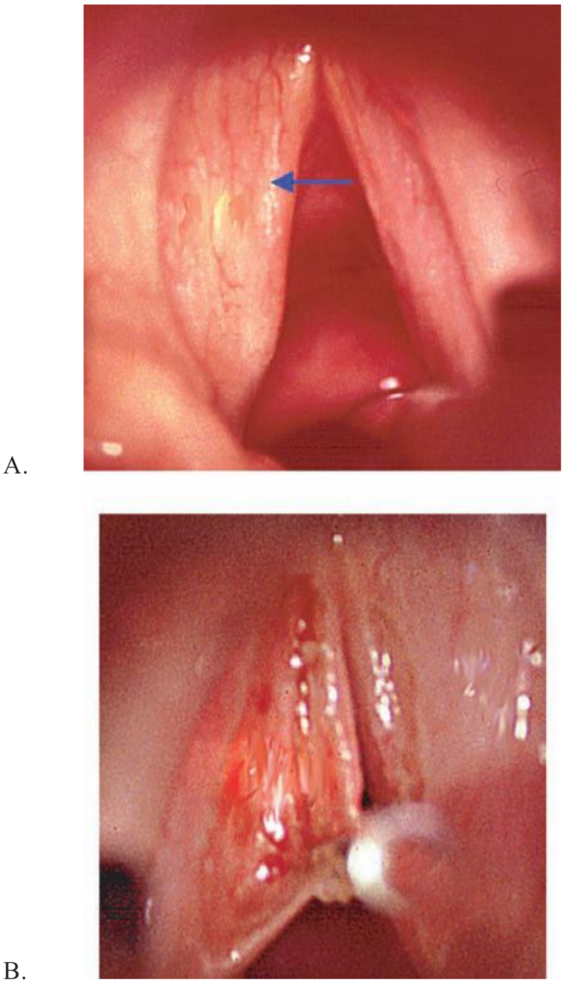


Fig. 1. Significant loss of tissue following cold instrument surgery on left vocal cord. A. Adherent scar. B. Epithelium raised with CO_2 AcuBlade, a pocket created and collagen injected submucosally.

6. Diseases and dysfunctions of laryngeal structures

Pathological processes affecting laryngeal structures and their classification are usually based on clinical appearance, tissue of origin, anatomical site, etc. However, the work presented here takes the application of laser technology as the starting point, and groups laryngeal pathology according to the features unique to laser management.

Most glottic lesions affect the phonatory function of the larynx. Surgical management aims at the removal of these lesions, and restores phonation. The procedure should be precise, and the healing process should not result in significant scarring or loss of tissue (Fig. 1). The microlaryngoscopic technique, with the proficient use of high-quality instruments by skilled surgeons, has done much to achieve this goal in the past few decades. The introduction of the CO_2 laser should be regarded as complementing the existing instrumentation, since it is not meant to replace well-established microlaryngoscopic techniques. Recognising this limited, but important

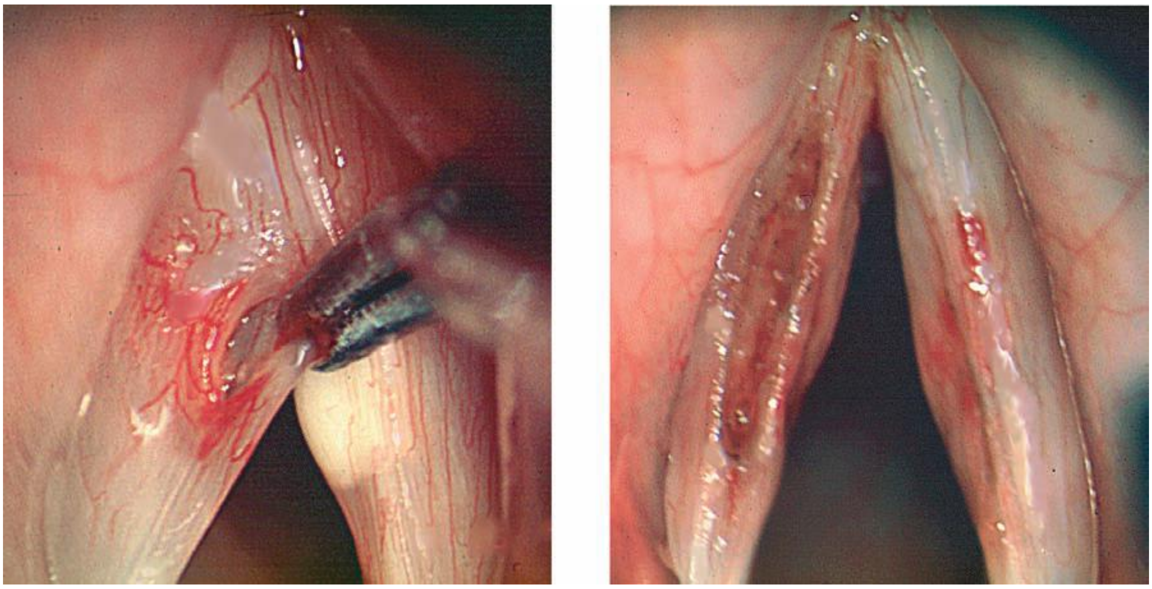


Fig. 2. Cyst of the larynx: superpulse technique results in very little charring of the cord.

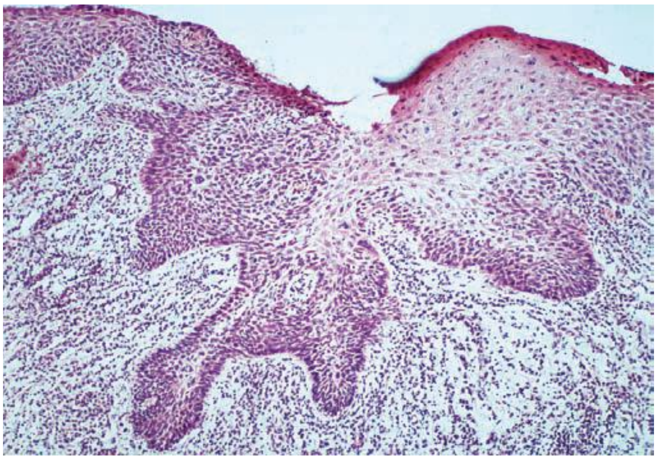


Fig. 3. Carcinoma in situ – frozen section. Coagulation depth ~ 50 µm. No difficulty is experienced in assessing the specimen.

role of the laser, the term 'laser-assisted procedure' seems more appropriate than 'laser surgery'. Thus, it is obvious that a newcomer to laser technology must first be competent in microlaryngoscopic techniques, and then learn about lasers and their tissue effects as continuing professional development.

The CO_2 laser was introduced into laryngeal surgery in the late 1970s and gained a foothold in the 1980s. In surgery of the vocal cord, the primary aim is to preserve the underlying vocal ligament. The technique involves using the beam in the superpulse mode (Fig. 2) with an intermittent exposure time of 0.1 seconds or less, and a low power setting of 2-3 W. The spot size at a working distance of 350 mm is 250 µm. These parameters achieve maximum ablation and a shallow depth of penetration. There is very little charring, and thus demarcation between normal and pathological tissues is easy to assess (Fig. 3).

This is even better accomplished by using the scanning technology (Acublade®, Lumenis, Santa Clara, CA). Acublade is a computer-guided scanner, designed for CO_2 laser-assisted micro-incision.

The scanner-assisted beam strikes the target as a straight or a curved incision line. The length of the incision line and the penetration of the beam can be adjusted.

The scanner-assisted incision and dissection are more accurate and require up to 30% less time than with a manually guided beam. Postoperative follow up is unremarkable. The coagulation zone is less than 10 µm for phonomicrosurgery and less than 20 µm for other surgical procedures. The scanner-assisted incision is more accurate than the one attained manually (Remacle *et al.*, 2005)

Some workers advocate further reduction of the thermal damage from conducted energy by pre-cooling the cords with ice-cold wet swabs held in position for a few seconds before the laser strikes. A shallow depth of penetration and thermal damage zone results in very little postoperative inflammatory response. Even extensive surgery for gross papillomatosis does not result in any significant postoperative oedema of the laryngeal airway, following the use of the CO_2 laser.

The integrity of the laryngeal airway is thus fully preserved obviating any need for elective or emergency tracheostomy, or re-intubation.

In the past decade, angiolytic lasers such as pulsed KTP-532 and Pulse dye laser (PLD) have been used in the office setting for certain pathological conditions, especially in papilloma management (Burns *et al.*, 2010; Zeitels *et al.*, 2009; Hartnick *et al.*, 2007). For in-depth reading on angiolytic lasers see Chapter 60.

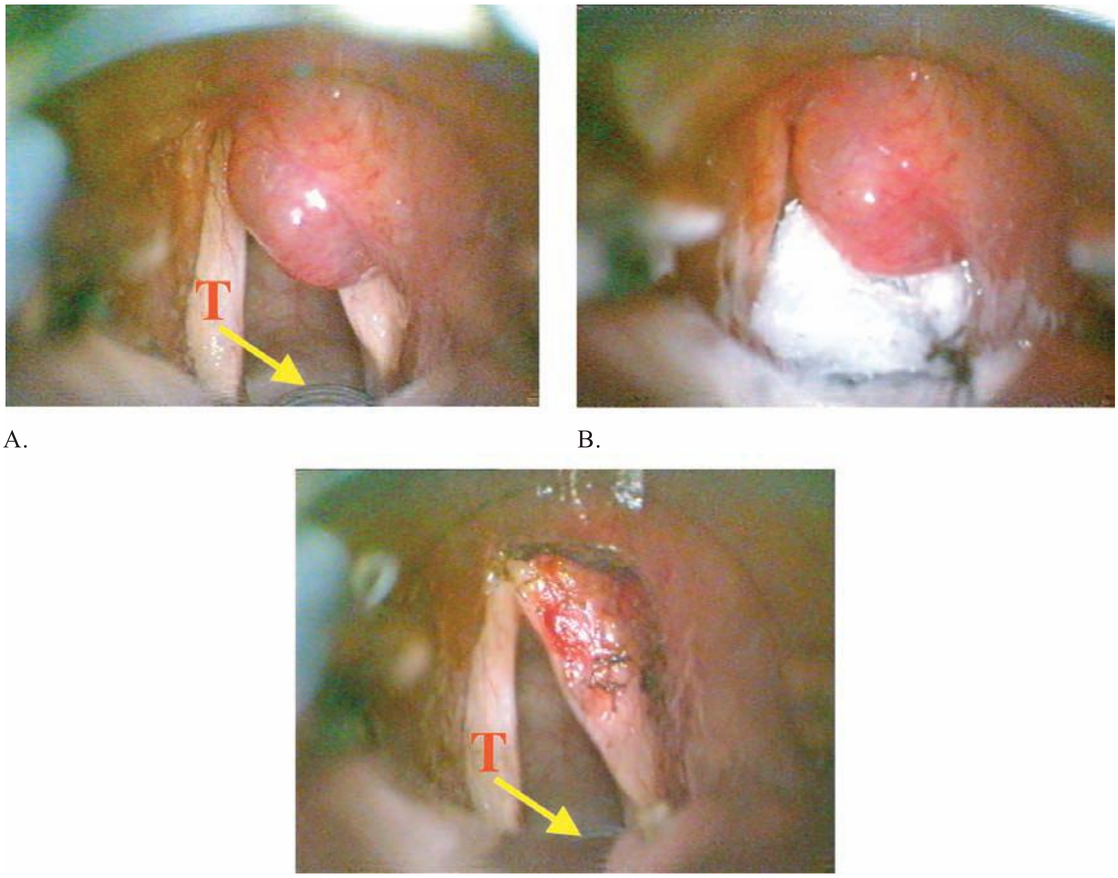
7. Access to the target tissue

Apart from precision for ablation, the CO_2 laser also offers other advantages. The free beam allows an unimpeded view of the target tissue since there is no carrier handle for the beam. It is also necessary to obtain a wide view of the target. Various laryngoscopes and suction-based instruments have been introduced and are described in Chapter 4. The CO_2 laser strikes produce smoke, which obscures the surgical field. This must be removed continually with dedicated suction units.

Hollow wave guides, specifically designed for transmission of the CO_2 laser are described in section Chapter 59.

8. Anaesthesia for laser laryngeal surgery

Although the target is fully visible when viewed co-axially with the operating microscope, the anaesthetic tube restricts full exposure of the pathological tissue to the CO_2 laser beam. A small paediatric cuffless tube can be positioned between the arytenoids and the trachea, and protected from laser strikes by a wet swab, which also acts as a cuff to a certain extent (Fig. 4). If the tube is made from flammable material such as PVC, it poses a significant risk of fire, and must be suitably protected with foil wrapping. Contrary to standard anaesthetic practice, the flammable tube must not be taped to the patient, so that it can be removed quickly and easily in case of ignition or fire. It is preferable to use tubeless



A.

B.

C.

Fig. 4. Ventricular cyst: a small cuffless LaserFlex paediatric anaesthetic tube (T) lies between the arytenoids and provides excellent view of the larynx. A. Small paediatric anaesthetic tube (T). B. Seal obtained with wet swab which also protects the cuff. C. Excision completed.

anaesthetic techniques whenever possible. For most laser surgical procedures on the larynx, we prefer to use high-frequency jet ventilation (HFJV) with an adult or paediatric metal catheter (Mayne-Remacle® catheter(Mayne *et al.*, 1991) that can be connected to most kinds of laryngoscope. A competent 'laser' anaesthetist will have a number of tricks up his or her sleeve to help the surgeon in this respect and he or she is regarded as an integral member of the laser team. Although the presenting symptom is hoarseness, the airway may be compromised. The various anaesthetic techniques are described in Chapter 6 and in Chapter 18 in paediatric laryngology. General anaesthesia (Remacle *et al.*, 1999) is still preferable for microsurgery of the larynx for a number of reasons. Preoperative assessment, based on videostroboscopy, may identify the vibratory disorders, but the precise nature and extension of the pathology may not be fully apparent. 'Instrument palpation' carried out under general anaesthesia is useful for accurate and precise assessment. The cords should be routinely everted and the subglottis examined. A 70° telescope, passed through the cords, will show any lesions in the subglottis and upper trachea. Examination of the upper aerodigestive and lower respiratory passages must be carried out in cases of recurrent respiratory papillomatosis (RRP), in order to exclude their involvement.

9. Intraoperative haemostasis

A further advantage of the CO_2 laser is its concurrent haemostatic effect. Blood vessels of less than 0.5 mm in diameter are sealed off due to shrivelling of the tissues. This is the case with the blood supply to most of the larynx and, therefore, intraoperative haemostasis is easily achieved with the CO_2 laser (Figs. 5 and 6). However, it is necessary to have monopolar diathermy, as sometimes, especially in the posterior larynx, the bleeding from large-sized vessels cannot be controlled with the CO_2 laser.

10. Postoperative recovery

Postoperative recovery is relatively uncomplicated. Any possibility of laryngeal spasm is avoided by meticulous cleaning of the operative site with wet swabs in order to remove charred tissue and debris. Fresh oozing is controlled with wet or adrenaline-soaked pledgets. Some anaesthetists spray the larynx with a topical anaesthetic agent in order to avoid spasm. Humidification in the ward is useful for the smooth recovery of small children who have undergone extensive surgery for laryngeal papilloma.

11. Indications for transoral laser laryngeal surgery

CO_2 laser surgery offers a distinct advantage in the management of phonatory disorders. It is also the method of choice for treating RRP. Many other lesions can also be tackled endoscopically.

For descriptive purposes, the various conditions may be conveniently grouped as follows:

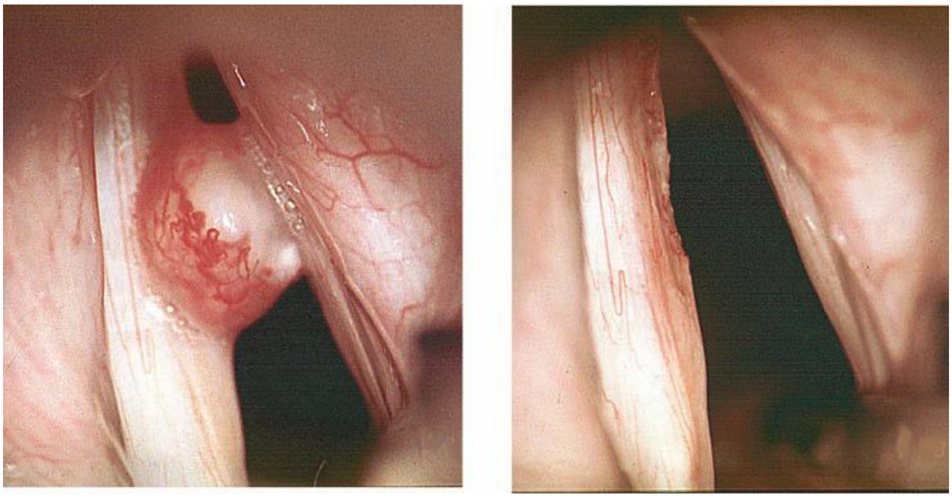


Fig. 5. Polyp, left vocal cord CO_2 laser provides excellent intraoperative haemostasis.

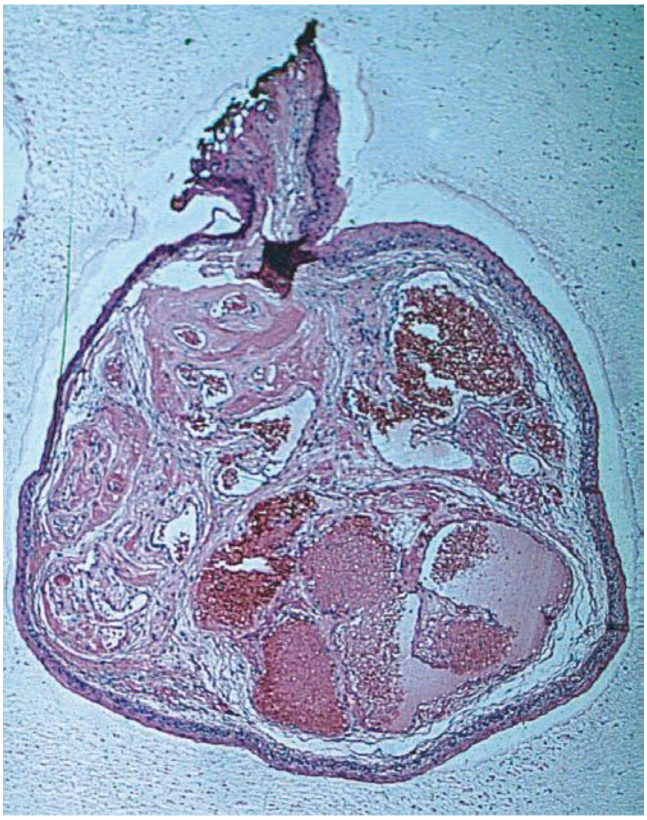


Fig. 6. Laser exicision of haemorrhagic polyp. The CO_2 laser is poorly absorbed by the red pigment of the blood. The coagulation depth is only ~ 50 µm when Acuspot is used.

11.1. Phonatory disorders

Grouped under this heading are conditions in which hoarseness is the main symptom. These include functional dysphonia plica ventricularis, exudative lesions of Reinke's space, intracordal mucosal or epidermal cysts, sulcus vocalis and vergeture, webs and mucosal bridge, etc. Management of these conditions needs careful attention to preservation of the phonatory mechanism, since the vocal ligament may be involved and irregularly shaped in the case of sulcus vergeture.

11.2. Cysts and tumours

This group includes epithelial, myogenic, cartilaginous, and neurogenic tumours. Cystic conditions, such as degenerative cysts and laryngocoele, are also included here. The symptoms consist of hoarseness but, as the tumour enlarges, symptoms of airway obstruction may appear. Endolaryngeal removal with the laser is usually possible. However, at times, it may be necessary to undertake a conventional external approach, particularly when there is a recurrence. Although RRP falls into the same category, it should be considered as a separate entity because of its propensity to affect the paediatric population, its distinctive course and frequency of recurrence.

11.3. Neuromuscular disorders

The most important neuromuscular disorder is bilateral abductor paralysis, causing acute or chronic dyspnoea. Endoscopic laser management is now the method of choice for this disorder, since a useful compromise between a good airway and good phonation can be achieved (Plouin-Gaudon *et al.*, 2005).

11.4. Chronic trauma and inflammatory conditions

Various forms of chronic laryngitis, such as pachydermia and leukoplakia, etc., are included under this heading. Although minor trauma leading to haemorrhage can usually be resolved, there may be scar formation that affects phonation.

Major trauma, such as fracture of the laryngeal framework, leads to gross fibrosis. Trauma from intubation takes various forms and results in synechiae, with hoarseness and dyspnoea. The endoscopic laser management of stenosis and webs, from whatever cause, may require additional procedures, such as the use of a keel (Lichtenberger, 1985).

11.5. Laryngeal cancer

The role of lasers in the management of laryngeal cancer has attracted much debate and controversy. A separate chapter (Chapter 11) has been allocated to discuss the various aspects of this in detail.

Although classifying laryngeal pathology as described above has some merit in that it avoids repetitions under individual headings, it must be emphasised that the division is not rigid. What follows, therefore, is a general philosophy of the management of each group of disorders rather than a critical appraisal of individual aetiologies.

12. Management strategy for laryngeal lesions

The leading symptom is dysphonia and the lesion is mostly confined to the epithelium. The pathological conditions and their management have been covered in detail in Chapter 8. The following is a brief account of these disorders.

Microsurgery of phonatory disorders and voice therapy are inseparable. This dual management strategy varies according to the lesion in question. In some cases, voice therapy is the initial treatment. When voice therapy fails, or the symptoms return due to recurrence, surgery is inevitable. In other cases, surgery is the initial treatment; this is followed by a course of voice therapy. The following examples illustrate the differences.

- When hoarseness is due to nodules, which are formed as a result of dysfunctional dysphonia, a course of voice therapy will resolve the condition in the majority of cases. Similarly, adequate improvement will follow voice therapy in cases in which hoarseness is due to minor sulcus, scarring, or chorditis vocalis. Surgical intervention should only be considered in cases which fail to respond, or which recur (Fig. 7).
- Hoarseness due to Reinke's oedema, cysts, or extensive sulcus will require initial surgical management. After a period of voice rest, a course of voice therapy is undertaken.

13. Cold instruments or the CO_2 laser

The choice of surgical instrument depends on the experience and expertise of the phonosurgeon (Benninger, 2000; Keilmann *et al.*, 1997).

In the hands of some surgeons, skilful surgery with cold instruments can produce very acceptable results (Sataloff *et al.*, 1992). For certain lesions, such as nodules, oedematous polyps, the CO_2 laser has no particular advantage over cold instruments (Figs. 8 and 9). However, we prefer laser instrumentation for certain conditions, such as haemorrhagic polyps, Reinke's oedema, mucous retention cysts, epidermoid cysts and sulci or sulcus vergeture (Remacle *et al.*, 2008; 2000). Unlike old-generation micromanipulators (Tanaka *et al.*, 1994; Rogerson

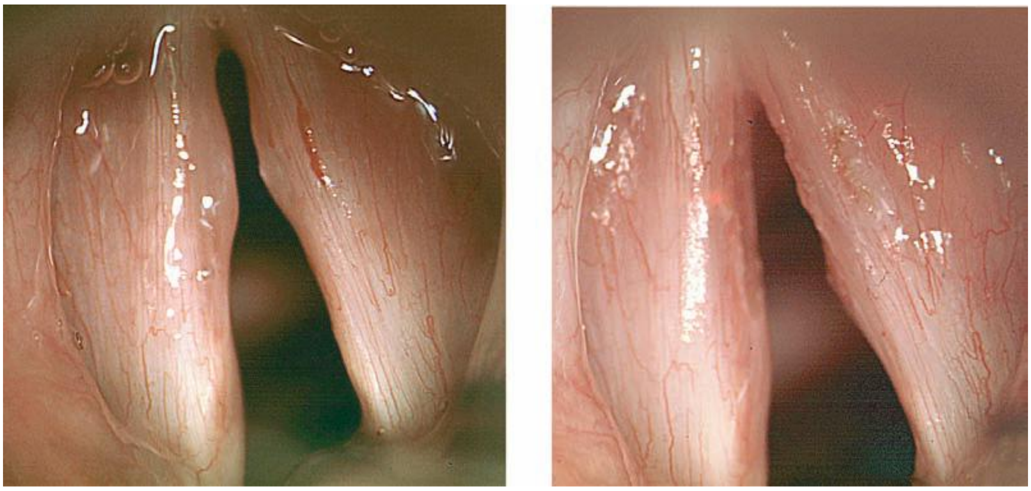


Fig. 7. Laser management of resistant vocal nodule.

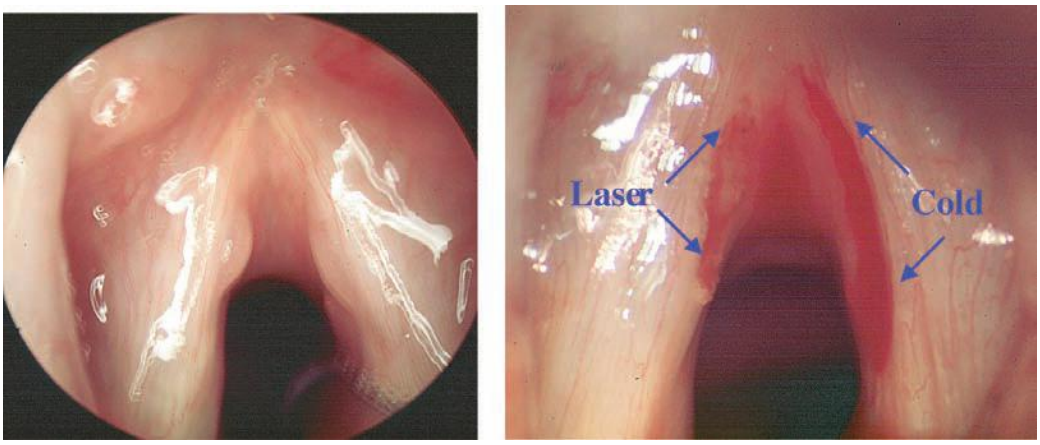


Fig. 8. Laser (left) and cold instrument (right) excision of vocal fold nodule.

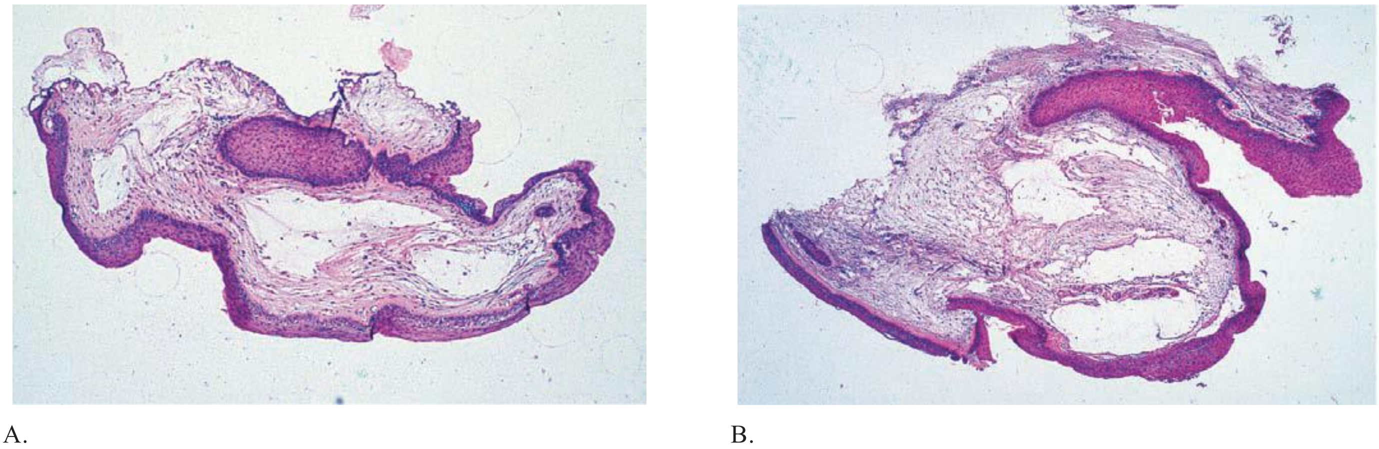


Fig. 9. Comparison of histopathological examination with laser excision (A) and cold instrument (B). No particular difficulty is experienced in assessing the laser-excised specimen. Coagulation depth < 50 µm.

et al., 1996), the micropoint manipulator of the newer generation CO_2 laser (Shapshay *et al.*, 1990) provides excellent precision. With the appropriate power setting in the pulsed mode, the capillaries are sealed off during surgery, facilitating incision and dissection. The char-free field allows an unimpaired view of the surgical progress, and ensures that the integrity of the vocal ligament is preserved (Frèche *et al.*, 1993; Giovanni *et al.*, 2000). This is even better with the scanning technology and the Acublade®, which allows greater precision than the micropoint (Remacle *et al.*, 2008).

The continuous mode should never be used on account of the increased irradiance of tissues in this mode. In the pulse mode, the thermal damage is only a few microns deep. The absence of adverse deep thermal effects after CO_2 laser-assisted micropoint incisions or dissections is demonstrated by Andrea's contact endoscopy (Andrea *et al.*, 1995), showing persistent microvasculature flux of erythrocytes within Reinke's space.

14. Powered instruments (Micro-debriders) versus lasers

Microdebriders have been developed over the past decade specifically for use in surgery of the larynx and lower airway. The microdebrider can be used for a variety of pathology, including papillomas, granulations, redundant tissue during supraglottoplasty and stenoses affecting any anatomical location from the larynx to the distal trachea (Kirse, 2009). Microdebrider excision of vocal fold for cancer is also feasible (Cheng and Soliman, 2010; Sant'Anna and Mauri, 2000), but violation of the epithelium and the lamina propria with muscle exposure can result in serious damage to the vocal folds. When using powered instrumentation the surgeon should use the utmost caution in the larynx to avoid gross injury resulting in scar with subsequent dysphonia (Mortensen and Woo, 2009). The new CO_2 scanning technology is much safer with this regard.

15. Beam parameters

The micropoint micromanipulator (Acuspot®, Laser Industries, Tel-Aviv) orients the CO_2 laser beam and, via a set of mirrors, provides the surgeon with a 250-µm spot size at a working distance of 350 mm. In the superpulse mode, the high power density results in precise ablation with very little thermal diffusion around the target. Thus, although the microscopic effect is still cellular vaporisation, the macroscopic cutting effect for dissection of the vocal cord epithelium is much more precise. The laser settings are usually 0.1 second exposure duration with power at 2-3 W, with a focused beam. If microvasculature coagulation is required, *e.g.*, for chorditis vocalis or Reinke's oedema before incision of the epithelium, then the laser is set at an 0.05-second pulsed exposure of 1 W with a slightly defocused beam.

However, these parameters are not applicable with the scanning technology. It is necessary to take in to account the length and the depth of the incision line, or the diameter of the circle and its depth, for the ablation mode. As a rule of thumb, the scanning technology results in an average of 100 µ depth of penetration for each pass of the CO_2 laser beam along the incision line or the ablation circle. The

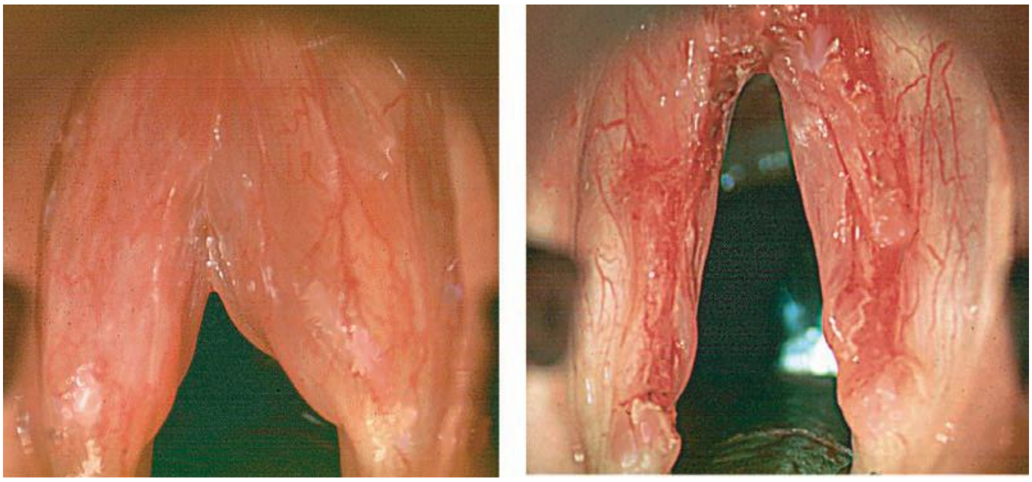


Fig. 10. Incision and suction, Reinke's oedema.

optimum power is calculated by the computer of the laser unit. It is power is usually 10 to 12 watts for the CW and the super-pulse or the ultra-pulse (Remacle *et al.*, 2005)

16. Laser surgical technique

Initial assessment is carried out to confirm the nature and extent of the pathology. Two different techniques are used: excision and dissection.

16.1. Excision

Excision is indicated for nodules, polyps, small sulci (referred to as opened cysts by Cornut and Bouchayer, 1992), mucosal bridges, mucous retention cysts, epidermoid cysts, and granuloma. The lesion is grasped with a Bouchayer® microforceps (Micro-France, Paris) and stretched towards the midline to define the plane between it and the vocal ligament. The laser is used in the pulse mode to vaporise the stretched fibres in the plane.

16.2. Incision

In contrast, incision is preferred for Reinke's oedema, large sulci and scarring. For Reinke's oedema, the microvasculature on the superior surface of the vocal cord is coagulated first. Then the epithelium is incised close to the lesion, along the length of the superior surface, from the vocal process to within 2-3 mm from the anterior commissure (Desloge and Zeitels, 2000; Remacle *et al.*, 1999) (Fig. 10). Once the incision has been made, the free margin is drawn towards the midline with a Bouchayer microforceps, and the gelatinous material is aspirated. The microflap is then re-draped. The excess epithelium, if any, is trimmed in order to achieve the best possible approximation of both incision edges. Provided a 2-3-mm strip of intact mucosa close to the anterior commissure is spared, surgery can be carried out simultaneously on both sides. For sulci or scarring, the technique developed by Bouchayer *et al.* (1985; Bouchayer and Cornut, 1992) is used. The incision starts at the superolateral edge of the lesion. Then, using a Bouchayer microforceps, the inner edge of the incision is grasped and careful dissection is performed along the epithelium. During dissection, it is advisable to grasp the entire dissected epithelium in order to separate it from the vocal ligament all the way to the inferior surface of the vocal cord. Small cottonoid pledgets, soaked in a solution of physiological saline and adrenaline, cooled to 5 °C, are used to control minor superficial bleeding and to remove tissue debris. After the completion of surgery, a few drops of slow-setting fibrin glue (Tissucol®, Immuno, Vienna) are applied, either for covering the excision field or for re-draping the microflap. The specimen is systematically oriented and sent away for histological examination. Accurate histological examination is not impaired by the presence of charring or coagulation, which only extend a few microns deep.

16.3. Vaporisation

In an obstructed airway, rapid bulk reduction can be achieved by vaporising the obstructing tissue with the acublade in circle mode. This quickly restores the airway for intubation and a more definitive management. See chapter 17 for further reading.

17. Restoration of defects in the vocal cord

Following surgery on the vocal cord when part of it has been excised, glottic incompetence will result. When the loss is small, this incompetence may not be apparent immediately on conclusion of the operation, but would be seen as atrophy of part of the cord at the review examination. In order to restore phonation, the body of the cord is made up by injecting it with various agents.

Synthetic implants provide a space occupying material or ‘fillers’, thereby pushing the vocal fold medially to restore glottic competency. Since some of these substances show a corpuscular consistency and a high viscosity they need to be deposited into the lateral paraglottic space. Therefore, the term ‘injectable implants’ has been coined for these materials (Sittel, 2009). The various tissue fillers and implants described below provide bulk in the paraglottic space so that the edge of the vocal fold approaches the midline once again, and meets the opposite side to restore glottic competency, vital for a good voice production.

17.1. Tissue fillers and biological implants

Several substances have been used, such as Teflon, fat, or glutaraldehyde cross-linked collagen (Gax collagen; ZyplastR, Collagen Corporation, Palo Alto, CA), synthetic calcium hydroxylapatite (CaHA) (Radiesse™ and Juliesse™; BioForm Medical, Inc., San Mateo, CA) and hyaluronic acid (Restylane; Q-Med AB, Uppsala, Sweden).

17.1.1. Gax collagen

Gax collagen seems to offer certain advantages over Teflon and fat. Collagen can be injected with a comparatively smallgauge needle (G27) within the lamina propria. It does not induce inflammation or formation of granuloma and is, consequently, the least harmful substance for the endoscopic management of glottis insufficiency. Unlike Teflon or fat, Gax collagen is immediately available should an unexpected need arise. We also find that the Gax collagen is preferable to Isshiki type-I thyroplasty for the correction of a glottic gap resulting from vocal cord atrophy. In fact, the latter disorder usually produces a smaller gap than vocal cord paralysis does. Although the use of fibrin glue is somewhat empirical, we subscribe to the view of Bouchayer and Cornut (1992) that it is useful for covering the site of the operation. It possibly acts as scaffolding for the regeneration of epithelium, and discourages any potential formation of granuloma. To date, no short-term or permanent side effects have been observed.

The injection is relatively easy in cases of Reinke’s oedema, where the tissue plane is usually well demarcated. However, in atrophic cases, injection at the precise site is difficult since tissue planes are ill defined and the injected material may leak. Creating a small pocket usually helps in this situation. The amount is determined by the size of the defect and visual appearance of the end result, but usually varies between 0.2 and 0.6 ml per vocal cord. In unilateral cases, the enhancement is carried out so that both cords appear equal in thickness. In bilateral cases, the material is injected so that the vibratory margins of both cords come into contact in the midline.

Ideally, at the end of the procedure, the cords should appear to be symmetrically full. The postoperative functional results after collagen injection remain stable for a period of 4.5 years (median value) in cases of glottic insufficiency due to vocal cord immobility (Remacle *et al.*, 1995). Gax Collagen is no longer available in Europe, but it is still marketed in the US.

17.1.2. Calcium Hydroxylapatite (CaHA)

Synthetic calcium hydroxylapatite (CaHA) is formed from calcium and phosphorous ions which are normal constituents of human teeth and bones (Rosen and Thedki, 2004). CaHA therefore has an excellent biocompatibility, ensuring that there are no antigenic or inflammatory responses.

Literature review

In a multi-centre prospective study, in a cohort of 68 patients, Rosen *et al.* (2007) reported significant patient satisfaction six months postoperatively in 56% and moderate satisfaction in 38%. Belafasky *et al.* (2004) reported satisfactory outcome in a cohort of 23 patients in respect of functional outcome following injection of CaHA for vocal fold augmentation. In a preliminary report on vocal cord augmentation with injectable CaHA, Rosen *et al.* (2004) found improved voice quality in patients with unilateral vocal fold palsy. According to Halpern *et al.* (2011), CAHa can stimulate local fibroblast activity and macrophage accumulation.

Indications

Gillespie *et al.* (2009) report that the injection of

CaHA was less satisfactory in patients with soft tissue defects because of poor retention of the paste in the scarred vocal fold remnant. The Transoral laser laryngeal surgery (TLLS) procedure was more likely to succeed in patients with paralysis and/or paresis than in patients with glottic soft tissue defects.

Method

CaHA can be injected into the vocal folds percutaneously as an office procedure, or trans-orally under a general anaesthetic. The implant itself (and not the carrier gel – see below) has a low resorption rate and therefore it may be regarded as a permanent implant. Injecting CaHA superficially under the cover results in impairment of vibrations. CaHA therefore must be injected *deep* to thyroarytenoid muscle just on the inside of the inner perichondrium, anterior and lateral to the vocal process.

The quantity and the location of the implant must be accurately controlled and over-injection avoided. A procedure under a general anaesthetic ensures accurate application in respect of dosage and location. Pressure on the thyroid ala facilitates the location by bringing the vocal fold well in to the operating view. Brunings-type laryngeal injector allows for precise implant delivery (Karl Storz, Tuttlingen, Germany). Each click of the Storz injector delivers 0.04 cc of implant.

Re-injection

CaHA contains about 30% carrier gel material which is resorbed within a short time (FDA, 2003; Kwon *et al.*, 2004; FDA, 2006). It may therefore be necessary to re-inject and to warn the patients to that effect. Rosen and Thekdi (2004) found vocal fold injection via endoscopic, direct laryngoscopy to be a more reliable procedure. They advocated slight over-injection (10% to 15%) which they found to provide optimum results.

Complications

Due to lack of antigenicity, there seems to be virtually no complication associated with the use of CaHA. The only possible poor result may be due to superficial injection or over-injection. Tanna *et al.* (2006) reported over-injection of CaHA in a single case of bilateral vocal fold paresis. The material was removed. The tissue around it showed FB giant cell inflammatory reaction. Chark *et al.* (2011) reported polyp formation in one case at the site of injection. Carroll and Rosen (2011) reported three complications in 108 procedures, but stated that the errors were technical in nature and by no means CaHA-specific complications or the ones that could have been avoided with other VF-injectable materials.

Any complication is more likely to be due to injection technique: superficial injection, over-injection, under-augmentation, or placement in the subglottic area. Carroll and Rosen (2011) emphasise that the placement of CaHA into the superficial layer of the VF should be strictly avoided. In case it is injected superficially, they advocate microflap technique for its removal. According to them, most reports emphasise the importance of a *'deep'* plane of injection when using CaHA to avoid this complication.

Long-term results

In a cohort of 108 procedures, Carroll and Rosen (2011) reported the average length of benefit to be 18.6 months, with a range of 8 to 36 months. There was a reported loss of benefit of CaHA in fourteen of 22 (64%) 'eligible' subjects. In their opinion, CaHA remains a safe and effective long-term vocal fold injectable with an average length of benefit of 18.6 months. They maintain that CaHA is a good long-term injectable option, with an excellent track record without concern for permanent or late complications.

17.1.3. Hyaluronic acid

According to Hirano (2005), hyaluronic acid, fibronectin, decorin, and various other extracellular matrix components, as well as collagen, contribute to determining the vibratory properties of the vocal fold mucosa. Alterations in these constituents are thought to affect the visco-elasticity property of scarred vocal folds. Innovative approaches have been developed, including administration of hyaluronic acid into injured or scarred vocal folds. Rudolf and Sibylle (2012) injected hyaluronic acid (Restylane) in 19 consecutive patients with unilateral vocal fold palsy and found that improvement in acceptable voice quality lasted for up to twelve months. They conclude that injection laryngoplasty with hyaluronic acid is a viable proposition in patients in whom the recovery is anticipated or a more definitive management is required at a later date.

Chhetri and Mendelsohn (2010) state that the use of a polymer such as hyaluronic acid appeared most promising for replacement therapy because it has unique viscoelastic properties. It is a natural component of the lamina propria (Korn *et al.*, 2011). It has hydrophyllic property, attracting water and thus improving the pliability of the lamina propria. In the authors' (MR) experience, the rate of resorption of the hyaluronic acid is comparable to collagen. However, as is the case with collagen, the rate of resorption is unpredictable and varies from patient to patient.

Surgiderm XP (Allergan, Irvine, CA) is an injectable hyaluronic acid more suitable for the vocal folds This hyaluronic acid is chemically reticulated with BDDE (butanedioldiglycidylether), as Gax-collagen was, to be more resistant to resorption

Hyaluronic acid is injected exactly as the collagen: lateral to lamina propria. However, in contradiction to collagen, it is not necessary to overcompensate. Its hydrophillic property will attract water in situ and make up any under-injection. If overcompensated in the first place, water absorption in to the material will cause it to balloon (Szkielkowska *et al.*, 2011).

17.1.4. Autologous fibroblasts

Chhetri and Berke (2011) expanded autologous fibroblasts in cell culture from punch biopsies of the buccal mucosa of five human subjects with vocal fold scarring. Three doses of 1-2 × 107 cells/mL were injected into the superficial lamina propria layer of each scarred vocal fold at four-week intervals. Patients were followed for 12 months following the first treatment. Mucosal wave grade improved and the improvement was sustained through month 12. They conclude that injection of autologous fibroblasts is safe, with improvement in vocal parameters.

17.2. Limitations of injectable implants

These fillers cannot replace the lost composite tissue such as the musculature, and a layered structure made of lamina propria and epithelial cover which together provide a vibratory layer. Synthetic materials used for providing bulk cannot restore the aerodynamic quality of the normal vocal fold. Matrix provided with these materials may result in further fibrous tissue. Finally, autologous fat is resorbed and needs replacement by further injections. In recent years, fabrication of tissue in a laboratory to produce more than one lineage to replace a complex structure such as the vocal fold has gained momentum. A brief description is presented in the following paragraphs.

17.3. Tissue engineering – basic concept

The term 'tissue engineering' is used to describe fabrication of biological tissue in a laboratory. Tissue engineering utilises living cells as engineering materials. The mesenchymal stem cells are harvested from bone marrow and fat. These cells can differentiate into all three basic embryonic tissues: ectoderm, mesenchyme and endoderm. Cell lineage thus fabricated can then repair or replace a variety of tissue types, including bone, cartilage, fat, and nerve. The term 'regenerative medicine' is usually used synonymously with tissue engineering.

17.3.1. Cell types for possible fabrication of vocal folds

Proposed cell types for vocal fold application have been native vocal fold fibroblasts, autologous fibroblasts from nonlaryngeal tissues, and adult adipose-derived stem cells (Long, 2010). Scaffolds were derived from decellularised matrix, biological polymers, and synthetic or chemically modified biopolymers. Chemical, mechanical, and spatial signals have been applied, such as hepatocyte growth factor, cyclic stretch, and air interface. Cells, matrix, and signals were combined – 'tissue engineering' – in an effort to replicate normal vocal fold tissue as closely as possible.

17.3.2. Fabrication of multi-layered tissue

Long *et al.* (2009) harvested adult adipose-derived stem cells and cultured these in fibrin hydrogels with various growth factors. Under experimental conditions, a superficial layer of epithelial cells grew over a deeper mesenchymal cell layer. Thus a three dimensional structure of fibrin and adipose-derived stem cells, resembling a bilayered structure of the vocal fold was created, opening up a possibility of reforming vocal fold with aerodynamic properties. Long *et al.* (2010) concluded that the three dimensional hydrogel of fibrin with adipose-stem cells resembled the lamina propria and the mucosal layers in microstructure and handling properties.

Adult stem cells derived from adipose tissue differentiated to epithelial and mesodermal lineage, organised by position. Epidermal growth factor and an air interface were required to produce epithelial differentiation.

In a scarred vocal fold, the vibration is impaired due to disrupted extracellular matrix of the lamina propria with increased collagen deposits and loss of elastic fibres. The end result of tethered mucosa

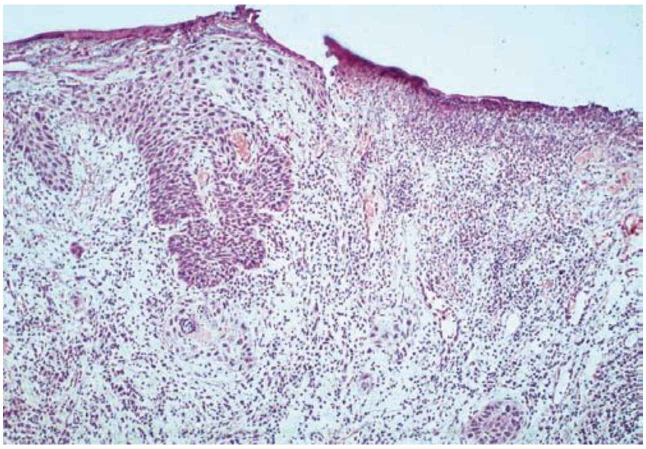


Fig. 11. Microinvasive carcinoma. Coagulation depth ~ 50 μm. No difficulty is experienced in assessing the specimen.

is not localized, and tethering extends to normal mucosa beyond the scarred area. Although attempts have been made to restore vocal fold mucosal wave by injection of cell or matrix, the evidence is limited (Long *et al.*, 2010).

The epithelial differentiation of adipose-derived stem cells for laryngeal tissue engineering introduces a new type of strategy of 'replacement' rather than repair or augmentation of vocal fold mucosa. It restores the lamina propria and the vibratory epithelium, en bloc. New, organised extracellular matrix and epithelium could prevent rescarring. Detailed discussion of this fascinating topic is beyond the scope of this work, and the interested reader is directed to the web for ever-increasing literature on regenerative medicine.

18. Postoperative care

Following phonosurgery, a few days of strict vocal rest is essential, the period of rest being dependent upon the type of pathology, extent of the operative procedure, and patient compliance.

The medical treatment consists of steroid aerosols and oral antibiotics for eight to ten days, at the end of which the assessment takes place. Thereafter the patient can resume phonation under the supervision of a speech therapist. Postoperative stroboscopic examination of small lesions shows good recovery of vibration amplitude and the return of the mucosal wave along the superior surface of the vocal cord. The vibration is usually symmetrical after surgery for nodules. However, the vibration may remain slightly asymmetrical following an intervention for polyps, mucous retention cysts, epidermoid cysts, or small sulci, but this asymmetry does not result in diplophonia.

19. Postoperative follow up

Recovery time is directly related to the extent of the surgical procedure. The more extensive the dissection, the longer it takes for the recovery of the vibration: three to four weeks for Reinke's oedema, and three to four months for large sulci or a sulcus vergeture. In the case of sulcus vergeture, although the vibration improves, it does not become normal. The spindle-shaped glottic aperture is smaller, but still apparent. Even if the amplitude returns to normal, the vibration frequently remains asymmetrical during phonation. Sometimes, a mucosal wave can be identified.

The minimum follow-up period is three months for Reinke's oedema, polyps or mucous retention cysts, four months for small sulci, five months for scarring or a sulcus vergeture, and six months for nodules.

20. Voice therapy

Following phonomicrosurgery, voice therapy is essential, the duration of which varies according to the severity of surgery and the individual patient. The sulcus vergeture requires prolonged speech therapy (up to six months) as this has to suppress the hyperkinetic compensatory mechanisms adopted by the patient before surgery. Furthermore, although the aim of surgery is correction of the glottic gap and fibrosis, the surgery itself induces a certain degree of fibrosis (although always less than the preoperative state).

21. Swallowing under supervision

In most cases of surgery on the vocal folds the swallowing is unaffected, always provided that the integrity of the arytenoids is not compromised. Swallowing is resumed the day after, under the supervision of speech therapist. However, following extensive surgery for cancer of larynx, the nasogastric tube is inserted for feeding. It also provides protection from aspiration. The feeding is resumed within a few days. The need for a prolonged percutaneous gastrostomy is exceptional.

22. Phonatory outcome

Following surgery for nodules, polyps, mucous retention cysts, or small sulci, there is subjective recovery to a normal voice. The outcome is maintained provided any functional dysphonic elements are properly corrected by voice therapy.

After surgery for Reinke's oedema, the pitch of the voice improves, particularly in women, and the voice quality remains satisfactory provided the patient does not smoke.

After intervention for sulcus vergeture, the patient perceives improved phonatory ease, reduced vocal fatigue, and a steady improvement of timbre. Breathiness, hoarseness, and episodes of vocal instability all decrease. The projected voice improves, but does not return to normal. Complete anatomical and physiological restoration of the vocal cord cannot be achieved, and therefore, it is necessary to explain the limitations of the phonatory outcome to the patient and to ensure compliance with extensive voice rehabilitation. Controversy remains on the quality of phonatory outcome following management of early glottic cancer with laser surgery versus, radiotherapy. Chapter 12 covers this topic in detail.

23. Histology of laser-excised specimens

Lawson and Remacle (1997) investigated the extent of thermal charring and its bearing on histopathological assessment following CO_2 laser surgery on the cord. One hundred and forty-eight procedures consisting of type-I cordectomy were undertaken with an Acuspot 712 micromanipulator (Sharplan Laser Industries, Tel-Aviv). This provided a spot size of 250 µm in diameter at a working distance of 400 mm. The superpulse mode was used for the shot-by-shot (0.1 second) cutting technique with 3-W power. The tissue was kept under constant tension throughout the procedure in order to minimise heat coagulation of the specimen and to prevent damage to the vocal ligament and muscle. The surgical specimen was placed on corkboard sheeting with correct orientation and tacked with small needles. Precise clinical and operative findings were sent to the pathologist with the specimen, in order to obtain an accurate histological diagnosis.

The depth of thermal charring was classified into three groups: less than 50 µm, between 50 and 100 µm, and more than 100 µm.

Accurate histopathological assessment was possible in all cases. Of the 148 cordectomies, 53.37% (*n* = 79) were reported to show simple hyperplasia, 20.94% (*n* = 31) were dysplasia (7.43% high grade), 24.32% (*n* = 36) were carcinoma, and 1.35% (*n* = 2) were benign granulomatosis.

The histopathological examination of frozen sections (*n* = 30) was not jeopardised by CO_2 laser surgery. The margins of resection were found to be positive at the first histological examination in 36.66% (*n* = 11) of the cases. The depth of the heat coagulation or charring on the margins was less than 50 µm in all cases.

Good collaboration between the surgeon and the pathologist is necessary, and the pathologist must have good experience in this field. The smaller spot size of 250 µm at 400 mm is an advantage for precise excision of the vocal epithelium. Higher power density permits the surgeon to use lower power (1-3 W), which minimises damage to the margins of the surgical specimen (Fig. 11).

The Acuspot 712 is a device with the convenience of a variable working distance of from 200-400 mm. Microlaryngeal surgery is possible at a working distance of 350 mm with low power (1-2 W) and minimal thermal tissue trauma. Unlike micropoint, the incision carried out with Acuspot does not have irregular margins. Its precision is increased further by using Acublade® technology (Remacle *et al.*, 2002).

Acublade is a computer-guided scanner designed for CO_2 laser-assisted microincision. Laser-produced coagulation thickness at the incision was measured on 41 operative specimens (Remacle *et al.*, 2005). The coagulation zone was less than ten micron for phonomicrosurgery and less than 20 µm for other surgical procedures. The scanner-assisted incision is more accurate than that attained manually.

The Acublade scanning system can be applied to both existing high-powered pulsed waves, the SuperPulse and the UltraPulse. Thirteen patients with bilateral and similar vocal fold lesions underwent operation, one side in SuperPulse mode and the other side in UltraPulse mode. The parameters for phonosurgery for SuperPulse were: depth of 0.2 mm, 10 W, single pulse, 0.10 second. For UltraPulse, the settings were: two passes, 10 W, single pulse, and 0.10 second (Remacle *et al.*, 2008). Incisions were sharper with UltraPulse, making the surgery easier, but at the first postoperative follow-up visit, after eight to ten days, no differences were observed in the appearance. The healing, and the vibration of both vocal folds were similar. Coagulation along the incision line was 25 micron for SuperPulse and 15 micron for UltraPulse (median values). In comparison with SuperPulse, the UltraPulse carbon dioxide laser made the procedure easier, but did not influence the eventual clinical outcome.

The Acublade® technology (Chapter 4) also has an impact on the reliability of the frozen section assessment. Remacle *et al.* (2010) retrospectively reviewed the records of all consecutive patients who underwent cordectomies with the CO_2 laser Acublade system (Lumenis, Santa Clara, CA) at their institution between January 2000 and 2008. Most patients did not have treatment with any other modality prior to laser surgery. The analysis of the data showed that 22.7% had severe dysplasia, 54.6% had T1 epidermoid carcinoma, 17.5% had T2 carcinoma and finally 5.2% had T3 carcinoma. The extent of the excision was type I cordectomy in 36.1% of patients, type II cordectomy in 18.6%, type III cordectomy in 10.3%, type IV cordectomy in 5.2%, type V cordectomy in 28.9% and type VI cordectomy in 1% of patients.

The mean number of submission of margins for frozen section per surgery was two. Routine histological examination confirmed the findings of frozen section in 94.8% of the interventions. Frozen section thus carries a high degree of reliability in laser-assisted cordectomies, when performed by an experienced team. It has a high negative-predictive value. It can limit the need, cost and emotional stress of 'second-look' surgery.

24. Conclusion

Transoral laser surgery has revolutionised the management of vast number of pathology affecting the larynx. In trained hands, management of Tis, T1 and even T2 glottic cancer is now becoming an accepted surgical modality. Although management of T3 and T4 lesions remains the preserve of a few experts, nevertheless, it has proved a feasible alternative in highly selected cases. On the downside, initial capital outlay is significant and the need for training in the safe and optimum use of lasers is real. However, in the long run, the phonatory outcome is superior and the hospital stay is much shorter. In fact, a number of procedures could be undertaken as outpatient, in the office settings under topical anaesthesia, as described in Section X, Part A.

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MCQ – 7. Transoral laser laryngeal surgery

1. The CO_2 laser offers the following advantages for transoral laryngeal surgery
    a. Good functional preservation of voice
    b. Minimum bleeding & charring during surgery
    c. Adequate access to all subsites including subglottic space
    d. Minimum postoperative morbidity
    e. All of the above

2. During vocal fold surgery, CO_2 laser is used in low power setting with superpulse mode & an intermittent exposure. This achieves
    a. Minimum postoperative scarring
    b. Adequate haemostasis
    c. Maximum ablation & shallow depth of penetration
    d. Minimum ablation & shallow depth of penetration
    e. Minimal ablation with little charring

3. During transoral laser laryngeal surgery, collateral thermal damage is reduced by
    a. Using CO_2 laser in continuous mode
    b. Using CO_2 laser in scanning mode
    c. Using hydro-dissection technique
    d. Using defocused beam
    e. Using focused beam

4. After transoral laser laryngeal surgery, the possibility of laryngeal spasm is minimised by
    a. Controlling oozing
    b. Spraying the larynx with topical anaesthetic agent
    c. Removing charred tissue from operative site with wet swabs
    d. Giving oxygen via mask
    e. All of the above

5. Which of the following conditions will require voice therapy as first line of treatment?
    a. Vocal fold cyst
    b. Sulcus vocalis
    c. Reinke’s oedema
    d. Vocal fold nodules
    e. All of the above

6. Which is the preferred method for phonosurgical technique?
    a. Use of Pulsed KTP-532 laser
    b. Use of Pulse Dye Laser (PDL)
    c. CO_2 laser delivery via hollow waveguide
    d. CO_2 laser free beam delivery with micromanupulator
    e. CO_2 laser with scanning attachment

7. During phonomicrosurgery CO_2 laser is not used for
    a. Excision
    b. Vaporisation
    c. Incision
    d. Coagulation
    e. Concurrent haemostasis

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8. Which of the following is the least used substance for the endoscopic management of glottic insufficiency?
   a. Gax collagen
   b. Teflon
   c. Autologous fat
   d. Autologous fibroblasts
   e. Hydroxyapatite

Chapter 8

Laser surgery for common laryngeal pathology

M. Remacle, A. Hantzakos, N. Matar and V. Oswal

1. Introduction

This chapter deals with the role of the CO_2 laser in some common as well as rare benign conditions affecting the larynx. Laser usage in chronic tropical inflammatory diseases in otolaryngology is covered in Chapter 56. Surgery on the free edge of the vocal cord needs much precision in order to maintain or restore integrity of the phonatory function. This is achieved by delivery of the laser energy co-axially, with micro manipulator attached to the operating microscope. Use of the scanning technology (Acublade®) allows safe, careful and precise surgery, even for lesions encroaching the lamina propria and in contact with the vocal ligament (Remacle *et al.*, 2005a).

Subglottic lesions are comparatively inaccessible with a free beam due to overhang of the vocal folds. The laser energy therefore needs to be taken to the target in the subglottic area via an optical fibre. However, the commonly available optical fibres are not transparent to the CO_2 laser. Flexible hollow waveguides, sometimes erroneously called optical fibres, are available. Their walls are lined by series of reflecting mirrors which take the energy to such inaccessible targets, but they have proved to be of limited value. A new CO_2 laser hollow fibre (Acupulse CO_2 waveguide®), resistant to power of up to 40 watt and working time of more than two hours, is now available. If the tip deteriorates during a surgical procedure, the fibre can be cleaved and reused in the same patient. However, a cleaved fibre is not recommended by the manufacturers for use in other patients, thus significantly increasing the costs for fibre-delivered CO_2 laser surgery. For further reading see Chapter 59.

Fibre transmissible lasers such as the KTP/532 or diode are a useful alternative (Bajaj *et al.*, 2010; Burns *et al.*, 2010), but these lasers should not be used on the free edge of the vocal fold on account of their comparatively deep penetration.

Apart from an adverse effect on phonation due to injudicious use of the laser technology, the only other concern is ignition of the anaesthetic tube. This issue has been addressed in detail in Chapter 6, and will not be repeated here. The use of lasers requires specific instrumentation, and this topic has been covered in detail in Chapter 4.

2. Functional dysphonia plicae ventricularis

Functional dysphonia plicae ventricularis (Maryn *et al.*, 2003) is synonymous with Koufman's maximum muscle tension dysphonia type II (MTD II) (Koufman and Blalock, 1991).

This voice disorder results from excessive lateral supraglottic stiffness affecting the ventricular folds due to spasmodic contraction of the external thyroarytenoid muscle. The dysphonia may be primary, or secondary, due to hypokinetic or organic lesions. Primary or secondary dysfunctional disorder should initially be treated with speech therapy. If this proves unsuccessful, CO_2 laser-assisted excision of both ventricular folds should be considered (Feinstein *et al.*, 1987). However, before embarking on surgical removal of the ventricular folds, it is

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prudent to assess the anticipated surgical outcome by injecting botulinum toxin into both ventricular folds.

Surgery consists of complete excision of both ventricular folds. Phonation is resumed only after adequate healing and epithelialisation of the excised area. Premature voice usage may predispose to formation of granuloma.

3. Spasmodic dysphonia (focal dystonia)

Spasmodic dysphonia (or laryngeal dystonia) is a voice disorder characterised by involuntary movements of one or more *intrinsic* muscles of the larynx during speech.

There are three types of spasmodic dysphonia (SD): adductor spasmodic dysphonia, abductor spasmodic dysphonia and mixed spasmodic dysphonia.

4. Adductor spasmodic dysphonia

In adductor spasmodic dysphonia, sudden involuntary muscle movements or spasms cause the vocal folds to slam together and stiffen. These spasms affect the normal vibratory mucosal movement during phonation.

The voice of an individual with adductor spasmodic dysphonia is commonly described as strained or strangled and full of effort. The speech may be choppy and sounds similar to stuttering. Words are often cut off or difficult to start because of the muscle spasms. Surprisingly, the spasms are usually absent while laughing, speaking at a high pitch, speaking while breathing and singing. However, singers can experience a loss of range or the inability to produce certain notes of a scale or with projection. Stress often worsens the muscle spasms.

4.1. Abductor spasmodic dysphonia

In abductor spasmodic dysphonia, sudden involuntary muscle movements or spasms cause the vocal folds to open. The vocal folds cannot vibrate when they are open. The open position of the vocal folds also allows air to escape from the lungs during speech. As a result, the voices of these individuals often sound weak, quiet and breathy or whispery. As with adductor spasmodic dysphonia, the spasms are often absent during activities such as laughing or singing, but singers can experience a loss of range or the inability to produce certain notes of a scale or with projection.

4.2. Mixed spasmodic dysphonia

Mixed spasmodic dysphonia involves muscles that open the vocal folds as well as muscles that close the vocal folds and therefore has features of both adductor and abductor spasmodic dysphonia.

4.2.1. Aetiology

The exact cause of spasmodic dysphonia (SD) is unknown. The National Institute of Neurological Disorders and Stroke (NINDS) and the American Academy of Neurology (AAN) classify SD as a neurological disorder. SD is formally classified as a movement disorder, one of the focal dystonias, and is also known as laryngeal dystonia. Some workers consider the aetiology of SD to be psychogenic, however, this view is not upheld by experts in the scientific community.

4.3. Treatment

4.3.1. Botulinum toxin-A injection

Botulinum toxin-A injection of the laryngeal hyperfunctional muscles has been found to be the treatment of choice to control the dystonic symptoms in most patients with spasmodic dysphonia. Botulinum toxin is a presynaptic neuromuscular blocking agent When injected intramuscularly in minute quantities, it produces selective muscle weakness (Blitzer *et al.*, 1998). The botulinum toxin injections generally improve the voice for a period of three to four months after which the symptoms gradually return. This treatment requires continual injections to maintain a good speaking voice.

4.3.2. Section of the recurrent laryngeal nerve

Section of the recurrent laryngeal nerve (Dedo, 1976) is now obsolete, being considered as too invasive and not without long-term limitations (Aronson and De Santo, 1983).

4.3.3. Selective bilateral denervation

Selective bilateral denervation of the adductor branch of the recurrent nerve and reinnervation of the distal nerve stumps with branches of the ansa cervicalis has been proposed for adductor spasmodic dysphonia but its application remains limited (Berke *et al.*, 1999)

4.3.4. External framework surgery
Expansion framework surgery or Isshiki type 2 thyroplasty is a possible open approach for midline lateralisation of the vocal folds (Friedrich *et al.*, 2001; Isshiki *et al.*, 2001).

4.3.5. Bipolar radiofrequency-induced thermotherapy
Bipolar radiofrequency-induced thermotherapy (RFITT) was proposed for inducing transorally a recurrent nerve coagulation (Remacle *et al.*, 2005b). The goal is to weaken the force of laryngeal closure during spasms by creating fibrosis of the terminal branches of one recurrent nerve through coagulation. Results remain stable for three to four years.

4.3.6. CO_2 laser-assisted myoneurectomy
CO_2 laser-assisted myoneurectomy is a feasible alternative to current methods to treat spasmodic dysphonia (Fig. 1). This was initially proposed via open approach through thyroplasty (Woo, 1990), but transoral approach is simpler and offers proven long-term positive results (Su *et al.*, 2010; Tsuji *et al.*, 2006).

The technique is mainly based on a partial CO_2 laser-assisted myomectomy of the inferior thyroarytenoid muscle (vocal fold muscle).

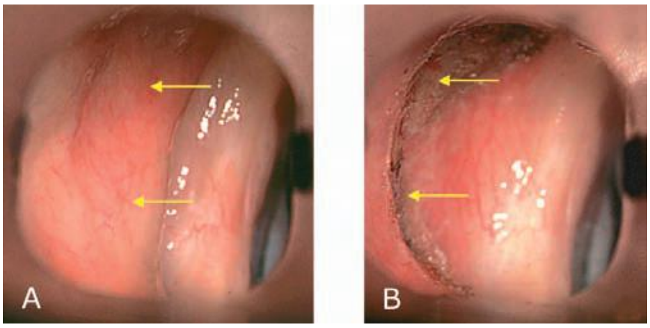

Fig. 1. Excision of left ventricular fold for resistant functional dysphonia plica ventricularis. Similar procedure is undertaken on the opposite side.

Only the lateral part of the muscle, involved in the adduction and tension activity of the vocal fold, is ablated. The medial part, more involved in the regulation of the vibration during phonation, is left intact. Bilateral surgery in one or two sessions is recommended.

5. Chronic inflammatory conditions

Chronic inflammatory conditions produce a variety of pathological lesions. Wegener's granuloma and Sarcoidosis, which may cause stenosis and compromise laryngo-tracheal airway are described in Chapter 16.

Inflammatory conditions which mainly affect the glottis result in hoarseness as predominant symptom. Some of these are described below.

5.1. Exudative lesions in Reinke's space

While functional dysphonia is a truly functional, and not an organic disorder, exudative lesions are pathological disorders. The term 'exudative lesion' broadly refers to a benign, acquired laryngeal lesion in Reinke's space (Hantzakos *et al.*, 2008). There are three macroscopic entities: Reinke's oedema, nodules and polyps.

The clinical presentation depends on the aetiological factors and also on the stage of the disease process at the time of consultation. The pathological changes consist of oedema, fibrosis and vasodilatation with haemorrhagic suffusion.

5.2. Vocal fold nodules

Vocal fold nodules are usually bilateral. They are excrescences located at the site of maximum vocal vibration, always superior to the free margin of the vocal cord, halfway between the anterior commissure and the vocal process of the arytenoid. Clinically, they are seen at the junction of the anterior one-third and posterior two-thirds of the vocal cord. Bernouilli's effect (sucking-in during the laryngeal vibration) as well as myoelastic-aerodynamic theory explains this location.

The force of impact on the vocal folds leads to submucosal oedema with subsequent nodule formation. In 20% of cases, the clinical pattern is associated with a sulcus (see below)(Remacle *et al.*, 1999). In adults, nodules mainly affect the female population (over 90%), especially in the active age group between 20 and 50 years of age. The patients are professional voice users, often teachers.

Management of fibro-oedematous or solid fibrotic organised nodules consists of surgical intervention (Remacle *et al.*, 2003) (see Fig. 7, Chapter 7). Following surgery, vocal rest of eight to ten days is advised. Voice therapy following a period of voice rest is then started, and continues until correct vocal usage is achieved. In well-established fibrotic nodules, a satisfactory result can only be achieved with a judicious combination of voice therapy and surgery, and the patient is counselled accordingly.

In children, surgery is an option only in refractory cases that fail to show any improvement whatsoever, following *exhaustive* voice therapy.

5.3. Vocal fold polyps

Polyps usually affect males between 20 and 50 years of age. They present in a variety of shapes and sizes. The aetiology of polyps is diverse and includes vocal abuse, acute vocal trauma, exposure to respiratory irritants, allergy, upper aero-digestive tract infection, tobacco and alcohol, endocrinopathy, and the presence of sulci. The appropriate treatment for polyps is microsurgery (Fig. 5, Chapter 7). Voice rest for eight to ten days after the operation is advised, followed by a course of voice therapy. This course is usually short, since the dysfunctional nature of the disorder is usually unimportant.

5.4. Reinke's oedema

Reinke's oedema is characterised by marked accumulation of exudative fluid and fibrosis within the entire vocal fold. The literature is rich in synonyms referring to this lesion: *e.g.*, polypoid chorditis, polypoid laryngitis, and pseudo-myo-oedematous laryngitis (the term used for bilateral vocal fold oedema seen with severe hypothyroidism).

According to the severity of the disease as determined by laryngeal appearance during endolaryngeal surgery, Yonekawa (Yonekawa, 1988) has proposed three types of Reinke's oedema: Types I, II and III. Similarly, Savic (1976) has proposed four grades. Grade 1 lesion is a very early lesion which is not detectable during indirect laryngoscopy. Strobosocpy shows blunt amplitude. Examination with microscope establishes the diagnosis of grade 1 lesion. Grade 2 represents a severe chronic oedema. Grade 3 corresponds with large, transparent oedema. Finally, Grade 4 corresponds with hyperemic, fluid-filled edematous spaces.

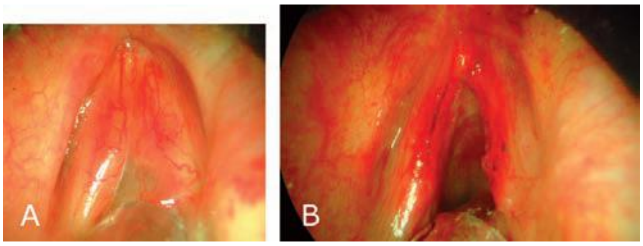

Fig. 2. Reinke's oedema. A. Pre-operative view; B. Post-operative view.

Simultaneous operations on both cords can be undertaken, provided 1 or 2 mm of mucosa at the anterior commissure is preserved so that a web does not form (Fig. 2).

Following postoperative vocal rest, voice therapy is indispensable: the treatment is lengthy and requires arduous efforts. A satisfactory voice is usually restored after three to four weeks.

6. Vascular lesions

Ectasias and varices of the vocal fold are microvascular lesions that often follow chronic abuse of the voice. In singers, they are typically the result of phonotraumatic shearing stresses and/or collision forces on the microcirculation within the superficial lamina propria. Varices are most commonly seen in female professional vocalists and may be secondary to repetitive trauma, fluctuations in hormonal levels, or repeated inflammation. These lesions can be debilitating in performing vocalists because of the effect of recurrent haemorrhage and/or as a contributing factor to the morbidity of other mass lesions such as polyps, nodules, and cysts.

Varices may also be associated with epidermoid cysts or sulci, in which case the varix is the 'sentinel' lesion (Bouchayer *et al.*, 1985).

Management of patients with a varix includes medical therapy, voice therapy, and occasionally surgical vaporisation. Indications for surgery are recurrent haemorrhage, enlargement of the varix, development of a mass in conjunction with the varix or haemorrhage, and unacceptable dysphonia after maximal and compliant medical and speech therapy. Both the 585-nm PDL and the 532-nm pulsed KTP lasers are found to be efficacious and relatively safe treatment modalities for vascular abnormalities of the vocal folds. Non-contact selective photoangiolysis of the aberrant vessels, without substantial photothermal trauma to the overlying epithelium and surrounding delicate superficial lamina propria, prevents recurrent bleeding, thereby allowing for optimal postoperative mucosal pliability and glottal sound production. The pulsed KTP laser is substantially easier to use because of its enhanced haemostasis due to its longer pulse width. Vessel-wall rupture, which is commonplace during use of the 585-nm PDL, rarely occurs during photoangiolysis with the 532-nm pulsed KTP laser. The CO_2 laser scanning micromanipulator (Acublade®) has also proved to be efficacious with very low thermal effect (± 15 μ) in the surrounding tissues (Remacle *et al.*, 2008).

6.1. Sulcus vocalis and sulcus vergeture

According to Bouchayer and Cornut (Bouchayer *et al.*, 1985), small sulci vocalis occur as the result of loss of part of the wall of a cyst of the vocal fold. The small portion that remains attached to the fold is a sulcus vocalis.

Although sulci vergeture were first identified at the start of the 20th century, Bouchayer *et al.* (Bouchayer and Cornut, 1992) emphasised their occurrence. Garel (1923) first named the groove 'vergeture' because it resembles the skin disorder of the same name ('vergeture' is the French term for 'stretch mark': '*striae atrophicae*').

According to Ford *et al.* (1996) the term sulcus vocalis has been applied to a spectrum of disorders ranging from minor vocal fold indentations to destructive lesions causing severe dysphonia. He proposes a clinically useful classification based on clinical and histopathological analysis: type 1 is a physiological variant accentuated by atrophy but with intact lamina propria; types 2 (sulcus vergeture) and 3 (sulcus vocalis) are characterised by severe dysphonia, loss of vibratory activity, and destruction of the functional superficial lamina propria. These latter cases respond favourably to microsurgery designed to remove destroyed tissue, release scar contracture, and promote mucosal redraping by undermining the surrounding mucosa (Remacle *et al.*, 2000b).

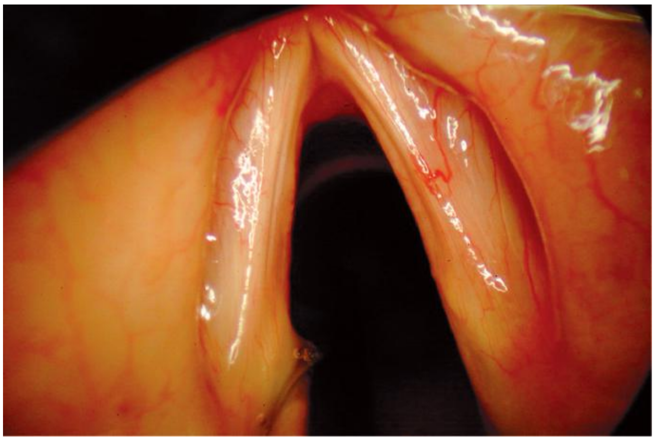

Fig. 3. Typical sulcus-vergeture. The bilateral furrows are clearly visible.

Sulci vergeture (Fig. 3) resembles the segment of an orange in shape. They are usually bilateral and cause a spindle-shaped glottic configuration. The mucosa in the base of the sulci is extremely atrophic and adherent to the vocal ligament. Although the adherent surface can vary in size, it usually involves the entire vocal fold. If the fibres of the vocal ligament beneath the atrophic mucosa are dehiscent; the muscle fibres are attached to the mucosa.

6.2. Mucosal bridge

According to the theory of Bouchayer and Cornut (Bouchayer *et al.*, 1985), a mucosal bridge arises from two apertures in a single epidermoid cyst: superior and inferior, since the mucosal bridge between the two apertures is always thick and hyperkeratotic. Some of them could develop from vocal fold microtrauma (Man *et al.*, 2010).

6.3. Anterior microwebs

Anterior microwebs are congenital malformations frequently encountered with sulci and cysts (Martins *et al.*, 2011). Anterior microwebs are also found in association with nodules (Bouchayer *et al.*, 1985; Ruiz *et al.*, 2006). When the microweb is large, it is removed during surgery for the main concomitant disorder. They may also develop from microtrauma, similar to associated lesions found with sulci (Ford *et al.*, 1994).

6.4. Bamboo nodes

Bamboo nodes are submucosal deposits, frequently associated with an auto-immune disorder. The leading symptom is dysphonia. Stroboscopy demonstrates a yellowish, often transverse appearance of the middle third of the fold, giving the characteristic appearance of a bamboo node (Perouse *et al.*, 2001). Whenever a patient with an auto-immune disease presents with a rough and unstable voice, laryngeal deposits should be suspected and a thorough laryngostroboscopic examination carried out. Because the patients may have hoarseness as their primary symptom, it is important for otolaryngologists to be familiar with this disorder. A combination of local laryngeal therapy with steroids and subsequent surgery seems to be a useful treatment approach for bamboo nodes (Schwemmle and Ptok, 2007). Its features are different from those of rheumatoid nodules (Murano *et al.*, 2001).

7. Chronic trauma

7.1. Haematoma

Acute vocal trauma combined with other risk factors (tobacco smoking, anticoagulant treatment, and allergic inflammation due to infection) may cause submucosal haemorrhage affecting the entire vocal fold. The onset is sudden and symptoms include dysphonia and odynophonia. Laryngoscopy reveals a typical red oedematous vocal fold. The initial treatment is conservative, *i.e.*, voice rest. If the haematoma does not resolve spontaneously within a few days, then surgical removal is advisable in order to avoid cyst formation within the vocal fold. The operation consists of incising the superior surface of the vocal fold and aspirating the blood that has accumulated within Reinke's space. The procedure is similar to that performed for Reinke's oedema of the vocal fold.

7.2. Ulceration and granuloma

Ulceration and granuloma result from injuries that induce epithelial abrasion and disruption of the basement membrane (Martins *et al.*, 2009). The granuloma develops when connective tissue proliferates through the basement membrane. The usual causative injuries include vocal abuse with posterior tension, pharyngolaryngeal reflux, and prolonged endotracheal intubation (Figs. 4, 5 and 6). More rarely, granuloma results from a foreign-body reaction, *e.g.*, after injection of Teflon or other synthetic substance (Baijens *et al.*, 2007; Chadwick *et al.*, 2007; Chheda *et al.*, 2008; Leuchter and Giovanni, 2009). Although ulceration and granuloma mainly affect the vocal process, they may also be seen on the anterior commissure or on the free margin of the vibratory segment of the vocal fold (Heller and Wohl, 1999).

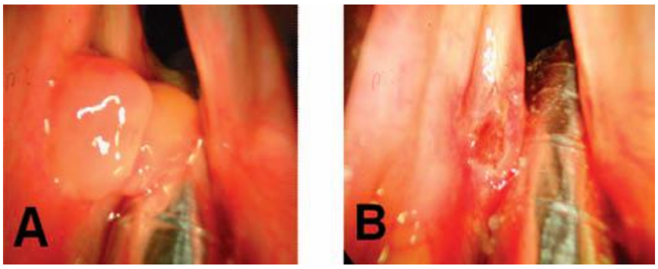

Fig. 4. A. Large granuloma on the superior surface of the vocal fold; B. Postoperative view.

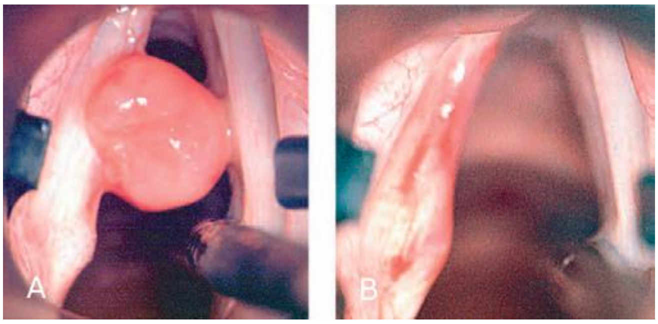

Fig. 5. A. Granuloma on the left vocal fold; B. Postoperative view.

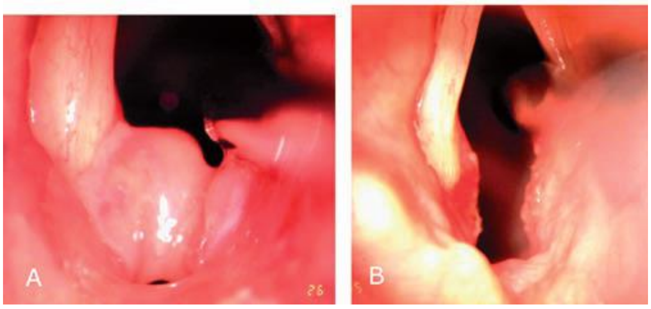

Fig. 6. A. Granuloma on the arytenoids; B. Postoperative view.

In mild cases (with hoarseness, but without dysphonia, dysphasia or dyspnoea), the treatment is essentially conservative: antibiotics, antireflux therapy, and steroid aerosols. In fact, because the excision of the granuloma involves denudation of the arytenoid cartilage, microsurgical intervention usually results in a high rate of partial or complete recurrence (Jaroma *et al.*, 1989). Speech therapy is often necessary. Ulceration may require surgery to remove its surrounding thickened rim (Havas *et al.*, 1999). The laser parameters are those used for CO_2 laser-assisted phonomicrosurgery. Recurrence of granuloma is not uncommon, due to the continuing aetiology of hyperkinetic dysphonia, exposed cartilage, and reflux. Local application of Mitomycin C (2 mg/ml) for two minutes after the excision might prevent its recurrence (Garrett *et al.*, 2001).

8. Scarring

Scarring results from an injury of variable severity sustained by the vibratory segment of the vocal fold. It affects Reinke's space and the vocal ligament. Prolonged endotracheal intubation or severe laryngitis with epithelial ulceration may also lead to scarring. It may result as a sequel to vocal fold surgery for dysplasia or carcinoma *in situ*. Injudi-

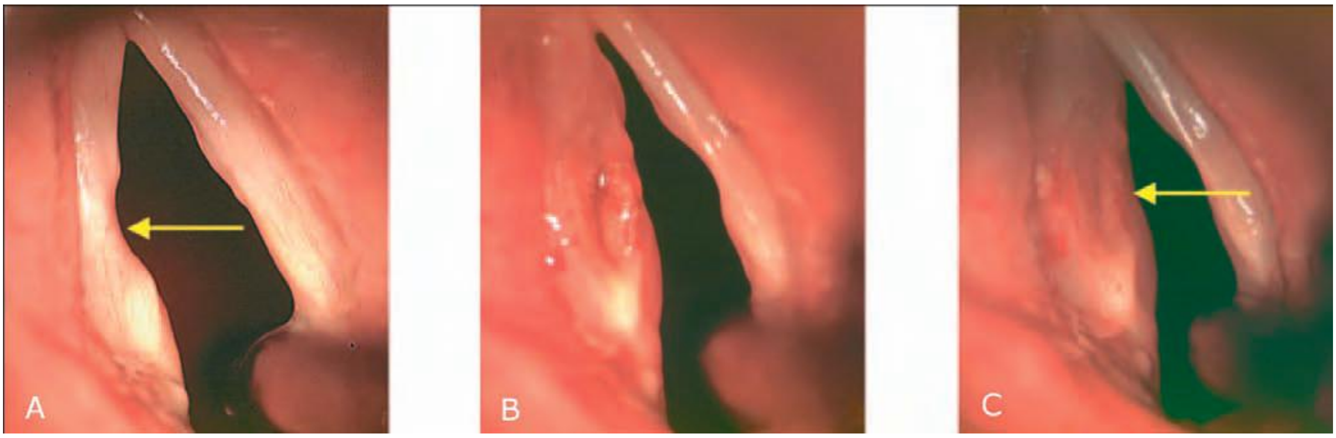

Fig. 7. Scarred left cord (A), made up with collagen injection (B)(C).

cious use of laser results in thermal trauma which heals with scarring.

The main symptom is dysphonia. On stroboscopic examination, amplitude and mucosal waves show asymmetrical vibrations. Vocal fold defects may be visible. As with sulcus vergeture, management is difficult (Hansen and Thibeault, 2006; Rosen, 2000). Steroid injection can be used on an outpatient basis using a rigid laryngeal telescope or with a flexible laryngoscope, under topical anaesthesia. This technique allows easy surgical manipulation with a good visual field and an easy, accurate approach to the lesion (Mortensen, 2010; Mortensen and Woo, 2009).

8.1. Surgical procedure

Surgical procedure begins with careful inspection of the vocal folds to confirm the working preoperative diagnosis of vocal fold scar. If both vocal folds show presence of scars, both are operated concurrently. Following the assessment, the epithelium is freed with the laser which helps delineating the dissection plane.

Using the scanning Acublade technology, in superpulse mode and single pulse of 0.1s, the incision line is set to one to two mm long, with a depth of incision of 0.2 mm. With this setting, the machine displays a power of 10-12 W on the panel. A cold steel dissector can help detach the epithelium from the vocal ligament. In case of vocal fold atrophy, which is frequently associated with a scarring process, the vocal fold volume is tentatively reshaped. Collagen is injected, as far as possible, in the deeper part of the lamina propria, until the vocal fold meets the midline (Fig. 7). After the collagen injection, the mucosal flap is redraped and secured in place with a few drops of fibrin glue (Tissucol, Baxter, Vienna, Austria).

8.2. Postoperative management

Postoperative vocal rest is recommended for eight days with instructions to strict compliance. Medical treatment is based on proton pump inhibitors until the healing is complete (Omeprazole, 20 mg b.i.d). Antibiotics are prescribed for four or five days, along with steroid aerosols for eight days. Voice therapy is started when the healing is complete and usually continues for three to four months.

Stroboscopic follow-up is performed once a month for four to five months when the final results, in terms of vibration improvement, are usually observed.

The management outcome, as in cases of sulcus vergeture, may not be altogether satisfactory, and the patient must be counselled accordingly. The maximum benefit is not apparent until four or five months postoperatively. Although complete restoration of the vocal fold may not be achieved, surgery does improve glottic closure and timbre. It also helps to reduce vocal fatigue and breathiness (Martinez *et al.*, 2010). As with sulcus vergeture, voice therapy is advisable to correct excessive reactive supraglottic contraction.

9. Subluxation of the arytenoid cartilage

Traumatic subluxation of the corniculate and arytenoid cartilage induces pain and discomfort during swallowing and even speaking. CO_2 laser resection of the corniculate cartilage, extended to the superior

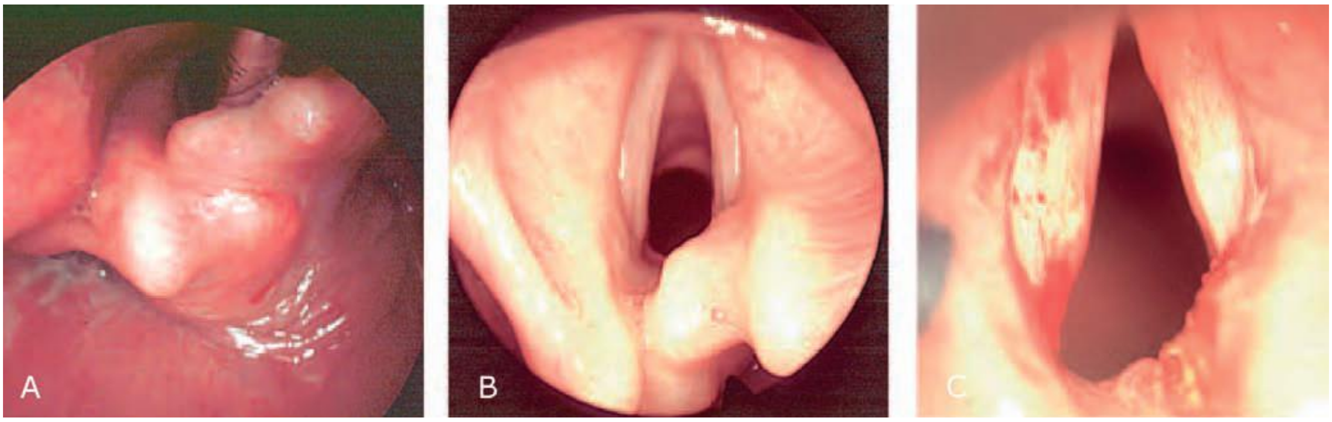

Fig. 8. A. Traumatic subluxation of the right corniculate and arytenoid cartilage, inducing pain and discomfort during swallowing and even speaking; B, C. CO_2 laser resection of the corniculate cartilage and superior part of the arytenoid cartilage solved the problem.

part of the arytenoid cartilage if necessary, can easily be carried out, resulting in marked improvement in symptoms (Fig. 8).

10. Augmentation of vocal fold

Following dissection and removal of epithelium, the current practice to make up a defect is by hyaluronic acid injection (Chhetri and Mendelsohn, 2010). Some authors advocate the injection of fat for restoration of vocal fold substance (see Chapter 12 for various methods for vocal fold augmentation).

11. Prevention and regeneration of mesenchymal tissue of the vocal fold: Literature review

Lee *et al*. (2006) evaluated autologous adipose tissue-derived stromal cells (ADSCs) to prevent vocal fold scarring and atrophy in the vocal cords of ten dogs. ADSCs were harvested from the adipose tissue of the inguinal area, cultured and mixed with atelocollagen. The mixture was injected in to the right vocal fold. As a control, only atelocollagen was injected in to the left vocal fold. Histopathological examination, showed large number of cells in ADSC-injected vocal folds eight weeks after the initial treatment, demonstrating the multipotential ability of ADSCs in the regeneration of injured vocal folds. They concluded that injecting ADSCs into a damaged vocal fold appeared to *prevent* vocal fold scarring and atrophy for 24 weeks after initial damage.

Svensson *et al*. (2010) injected human mesenchymal stem cells into scarred vocal fold of rabbit and reported enhanced healing of the vocal fold with reduced lamina propria thickness, increased collagen type I content and restoration of the viscoelastic function. Experimental results suggest that administration of Hepatocyte Growth Factor (HGF) may also have therapeutic potential in the treatment of chronic vocal fold scarring (Kishimoto *et al.*, 2010).

Ohno *et al*. (2009) state that appropriate scaffolding is necessary for the stem cell implant to achieve optimal results. They used atelocollagen sponge as scaffolding since it has large pores that permit cellular entry and is degraded *in vivo*. Bone-marrow-derived stromal cells were seeded into Terudermis and incubated for five days. Their survival, proliferation, and expression of extracellular matrix were examined. Bone marrow-derived stromal cells adhered to Terudermis and underwent significant proliferation. The data suggest that Terudermis may have potential as stem cell implantation scaffolding for the treatment of scarred vocal folds.

Kishimoto *et al*. (2009) implanted atelocollagen sheet into lamina propria of the vocal folds in six post-cordectomy patients with scar or sulcus vocalis. A microflap was raised, the scar tissue was dissected, atelocollagen sheet was implanted and the wound was closed (Fig. 9).

Vocal function was evaluated before and after surgery by stroboscopic examination and by aerodynamic and acoustic analyses. They reported gradual improvement in aerodynamic and acoustic parameters over a year. Stroboscopic findings also revealed gradual improvement of vibratory proper-

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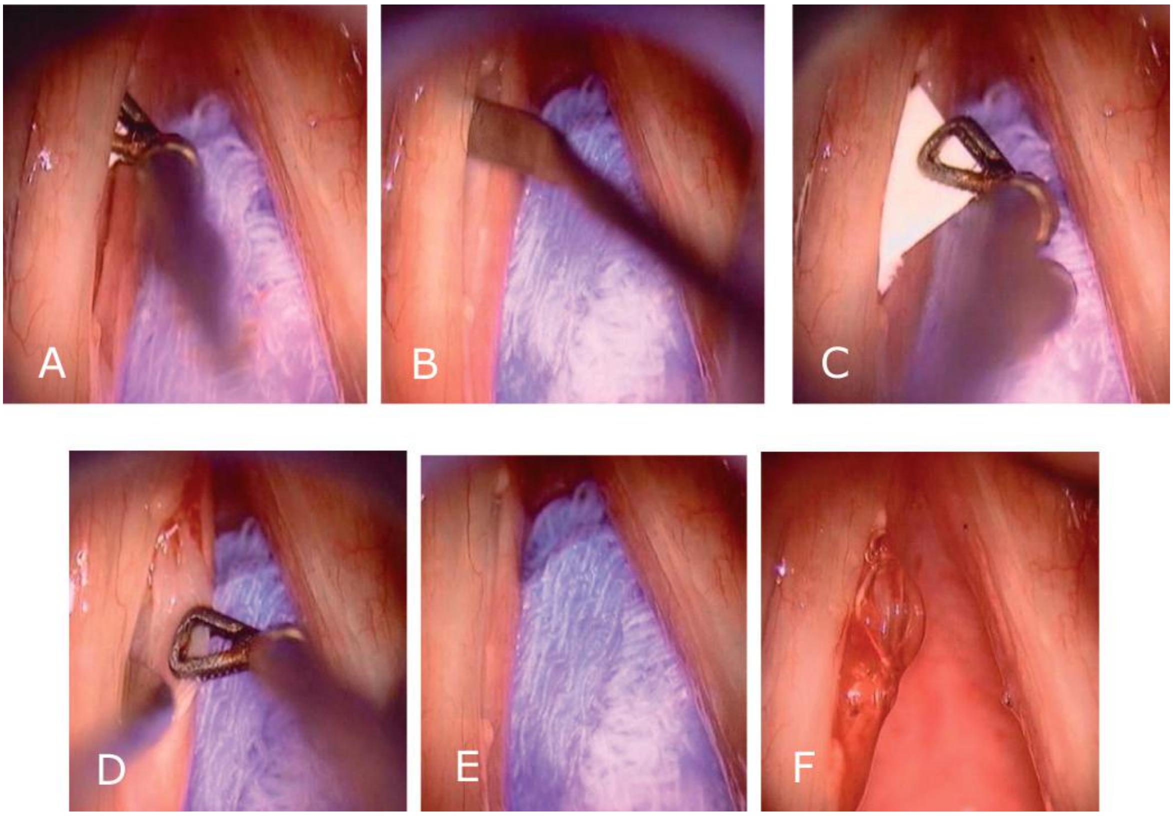

Fig. 9. A-F. Atelocollagen insertion. (Courtesy: Gandhi S.)

ties in most cases. They concluded that implantation of atelocollagen sheet may have restorative effects on vocal fold scarring and sulcus vocalis in terms of tissue properties and function of the mucosa.

However, Kimura *et al.* (2010) examined the functional biomechanical properties of several injectable biomaterials currently or potentially used for vocal fold augmentation. These included 3% bovine collagen (atelocollagen), micronised AlloDerm (Cymetra; LifeCell Corp., Branchburg, NJ), calcium hydroxylapatite (CaHA) (Radiesse; BioForm Medical, San Mateo, CA), and 2.4% cross-linked hyaluronic acid (HA) gel (Juvéderm; Allergan, Inc., Irvine, CA). Their functions of frequency covering the phonatory range were compared to those of the human vocal fold cover. They concluded that none of them were rheologically optimal for the functional reconstruction of the vocal fold lamina propria.

12. Benign laryngeal tumours

A variety of benign neoplastic laryngeal lesions can occur, but they are rare. A detailed description of their natural history, pathogenesis, macroscopic and microscopic appearance is outside the scope of this volume. Suffice it to say that their almost bloodless, and therefore precise and complete endoscopic removal has been made possible due to the unique properties of the CO_2 and other fibre-guided lasers. However, access and tumour size and the type of pathology such as chondroma may sometimes be prohibitive for adequate and complete endoscopic removal and a conventional external approach will be necessary. These tumours may recur because of inadequate endoscopic removal. In such cases, the possibility of malignant transformation should be ruled out by careful and competent histopathology. A few common conditions are described below.

13. Cysts

Broadly speaking, there are two types of cyst affecting the larynx: the ductal retention cyst and the malformed saccular cyst arising from the ventricular appendix (Nussenbaum *et al.*, 2002). Clinically, saccular cysts resemble laryngocoeles (Barnett *et al.*, 2001).

Mucous retention cysts result from obstruction of the duct of the mucous gland of the vocal fold. This obstruction is either post-inflammatory or caused by repetitive microtrauma (Beaver *et al.*, 2005).

CO_2 laser-assisted endoscopic treatment consists of the complete removal (Ostfeld *et al.*, 1990) or extensive marsupialisation of the cyst (Myssiorek and Persky, 1989). The procedure is ideally performed with the Acublade in section and ablation and in CW. A suction-coagulation cannula is used to control any bleeding.

13.1. *Mucous retention cysts*

Microsurgical removal is the usual treatment for mucous retention cysts (see Fig. 2, Chapter 7)(Figs. 10, 11 and 12). In order to avoid recurrence, it is advisable to remove the entire cyst wall. Any contact lesion should also be removed simultaneously. Voice therapy begins after the postoperative period of vocal rest.

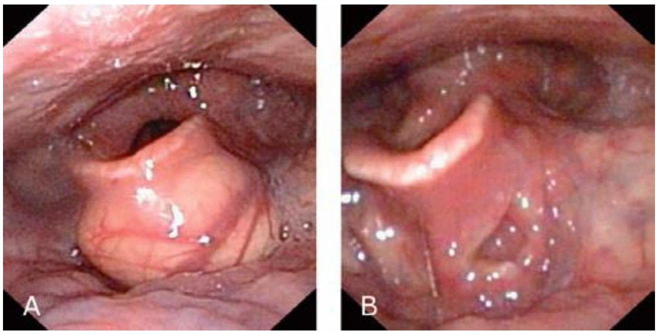

Fig. 10. A. Vallecular cyst; B. After marsupalisation with CO_2 laser hollow waveguide.

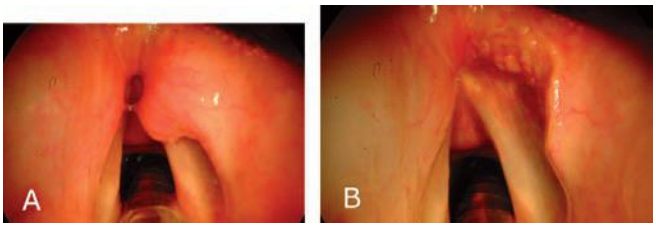

Fig. 11. A. Ventricular cyst; B. Postoperative view.

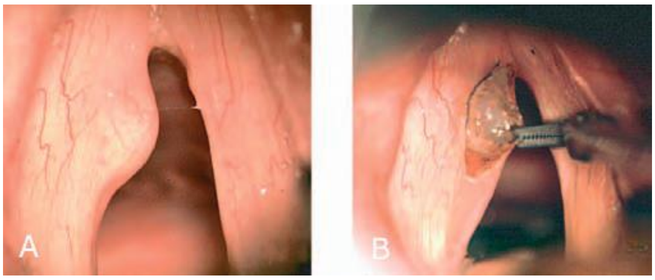

Fig. 12. Mucous retention cyst, left fold. A. Mucus retention cyst; B. Postoperative view.

13.2. *Intracordal epidermoid cysts*

Epidermoid cysts (Fig. 13) are cystic cavities lined by stratified squamous epithelium, with several cell layers growing centripetally as keratin and cholesterol crystals accumulate.

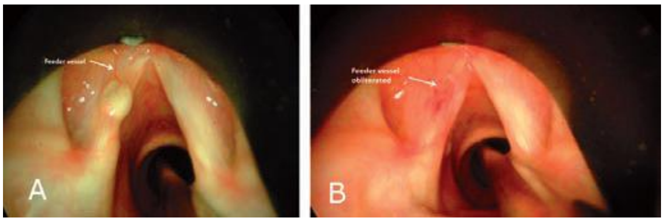

Fig. 13. A. Epidermoid cyst, pre-operative, note feeder vessel (see arrow); B. Postoperative, note obliterated feeder vessel (see arrow).

They are typically located in the superficial layer of the lamina propria, but can extend to involve the middle and rarely the deep layers of the lamina propria. They may be congenital in origin or secondary to trauma. They represent an entity in a continuum of lesions. The cysts are filled with a thick white material produced by epithelial desquamation. Cholesterol crystals may also be present.

If the cyst ruptures spontaneously, a mucosal bridge or a sulcus might develop (Bouchayer *et al.*, 1985).

14. Laryngocoeles

Laryngocoeles are air-filled, abnormal dilatations of the ventricular appendix at the roof of Morgagni's ventricle, with a patent isthmus (Dursun *et al.*, 2007).

Suggested aetiologies include congenital enlargement of the saccule, weakness of laryngeal tissues and increased intralaryngeal pressure. Laryngocoele can also develop after neck surgery (Marom *et al.*, 2010). A laryngopyocele forms when a laryngocele, as a dilatation of the laryngeal ventricle, becomes infected and fills with mucopus (Ludwig and Chilla, 2010).

Internal laryngocoeles (Martinez *et al.*, 2002) are removed endoscopically with a large portion of the ventricular fold – Kashima's vestibulectomy. The initial treatment of external laryngocoeles is endoscopic removal of the false fold, followed by deflation and marsupialisation (Fig. 14). The external approach is only advised if the endoscopic technique fails (Vengerovich *et al.*, 2010).

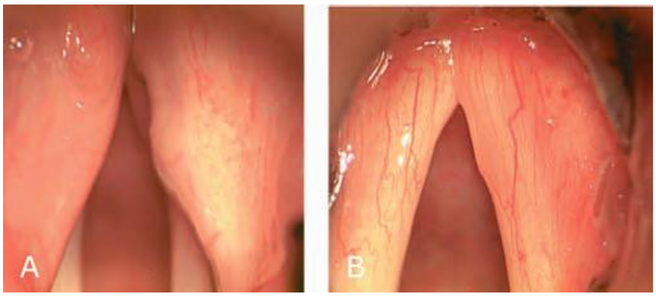

Fig. 14. Bilateral laryngocoele, A: preop, B: postop.

15. Chronic hyperplastic laryngitis

The term chronic hyperplastic laryngitis encompasses a number of clinical conditions, including leucoplakia, white hyperplastic laryngitis, red hyperplastic laryngitis, erythroplakia, and speckled erythroplakia. Clinical examination alone, or in conjunction with stroboscopy, confirms the hyperplastic appearance, but cannot differentiate between innocuous hyperplasia, dysplasia of varying severity, carcinoma *in situ* and a microinvasive carcinoma (Damm *et al.*, 1997). Furthermore, there is no correlation between the presence and severity of epithelial hypertrophy and the incidence of a malignant change (Maurizi *et al.*, 1996). Therefore, it is imperative that the lesion be excised in its entirety, oriented, and submitted for histological diagnosis (see Fig. 5c, chapter 11). A simple punch biopsy of one or several areas may not provide accurate assessment of the *whole* lesion, and would not allow correct management of the pathological process (Remacle *et al.*, 1997). In a series of 93 cases of chronic hyperplastic laryngitis, the excised specimens of the entire epithelium showed carcinoma or a dysplasia in as many as 50% of cases. The other 50% were cases of hyperplasia (Lawson *et al.*, 1997).

Management consists of a microsurgical technique that minimises damage to the underlying normal tissue, and preserves function.

The CO_2 laser Acublade™ micromanipulator provides a spot size of 250 μm at a focal length of 350 mm. The beam parameters are similar to those used for phonosurgical techniques. The beam is used in the superpulse mode, with an exposure time of 0.1 second. The incision line is usually between 1.5 and 2 mm long, with a power setting of 12 to 16 watts (Remacle *et al.*, 2005a). These settings limit the thermal coagulation zone to under 50 μm (Remacle *et al.*, 2008), and thus prevent thermal damage to the underlying vocal ligament. Moreover, the shallow thermal damage zone does not interfere with the accurate histological interpretation of excised specimens, even of frozen section (Remacle M *et al.*, 2002). Removal of the whole lesion is thus both diagnostic and therapeutic, since healing is by re-epithelialisation of the vocal ligament (Remacle, 2008; Remacle *et al.*, 1997).

Complete healing, followed by speech therapy, ensures satisfactory voice recovery. The European Laryngological Society (Remacle *et al.*, 2000a; Remacle *et al.*, 2007) has introduced a new nomenclature for excision of the entire epithelium, namely 'subepithelial cordectomy', and has included it within the overall classification of endoscopic cordectomies. The old terminology for this procedure was 'stripping' or 'decortication'. Subepithelial cordectomy is primarily diagnostic. When histology confirms that the pathology is limited to the superficial layer, without involvement of Reinke's space or the vocal ligament, the procedure becomes therapeutic. Any deeper extension of the disease requires further surgical management with various types of cordectomy, as appropriate.

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MCQ – 8. Laser surgery for common laryngeal pathology

1. Following lasers are suitable for transoral endolaryngeal laser surgery
    a. KTP
    b. Diode
    c. CO_2
    d. Nd:YAG
    e. Pulse dye laser

2. The most suitable laser for laryngeal surgery is the CO_2 laser because
    a. It can be delivered via specially adopted optical fibres
    b. Its scatter within the tissue is most suitable for dealing with bulky tumours
    c. Due to its shallow penetration, it is the laser of choice for the management of pathology on the free edge of the vocal fold
    d. Its energy can be used in free mode, thus providing unobstructed view of the target
    e. It can be used in the subglottic space in the free mode for selected lesions

3. Although the CO_2 laser the most common laser used for laryngeal surgery, it is also the most hazardous laser because
    a. Its red beam is reflected from the shiny surfaces and can ignite the anaesthetic tube
    b. In the free mode, its beam is collimated and thus retains much power over a considerable distance
    c. It causes much charring and collateral damage if used in continuous mode at high energy setting on fibrous tissue such as a web or fibrotic stenosis
    d. It can cause *retinal* damage if eyes are not protected with dedicated eyewear

4. The CO_2 laser should ideally be used in vocal nodules
    a. When conservative management such as voice rest fails
    b. As first line of treatment since it causes a very shallow depth of thermal damage zone
    c. Since it restores normal voice within a week after the operation, without a need for voice therapy
    d. In all cases of fibrotic nodules
    e. To remove them even if they are present on both cords, at the same session

5. In Reinke's oedema cases, the laser should be used to
    a. Vaporise the mucosa so as to sculpt a normal looking cord
    b. Incise the oedema and contents evacuated with suction.
    c. Evaporate the glue like contents until the a normal looking cord is reached
    d. Sever redundant mucosa so the edges of the incision can be aligned draped back and held in position with fibrin glue.
    e. Treat only one side at a time to avoid synechiae formation

6. For ectasias and varices,
    a. There is no difference in the mode of action of the CO_2 laser and the pulse dye laser (PLD) since both lasers blanch the blood vessel
    b. The CO_2 laser vaporises the blood vessel completely along with its content
    c. The CO_2 laser is an effective laser to cause angiolysis by coagulating the blood in microvasculature which results in visible blanching of the blood vessel
    d. Intraoperative haemostasis is achieved with the CO_2 laser due to shrivelling of the blood vessels
    e. Initial ablation of feeder vessel is useful to miminise bleeding during excision of an associated mass lesion such as haemorrhagic polyp

7. For ectasias and varices, the main difference in the action of the CO_2 laser and the angiolytic laser is:

   a. The CO_2 laser energy is confined to the blood vessel being treated due to selective absorption by water
   b. The angiolytic laser energy is confined to the blood vessel being treated due to selective absorption by haemoglobin
   c. The CO_2 laser action is thermal whereas the angiolytic laser action is photoangiolytic
   d. Since the action of the angiolytic laser is confined to the inside of the blood vessel wall, there is no thermal damage to the surrounding normal tissue
   e. Ideally, all ectasias and varices, particularly those in the vicinity of superficial lamina propria, should be treated with angiolytic lasers to achieve optimum phonatory outcome

8. Arytenoid granuloma
   a. May result from intubation trauma, vocal abuse and reflux
   b. Complete excision along with the mucosa covering the cartilage assures cure
   c. Application of Mitomycin-C to the operation site may discourage recurrence
   d. Recurrence is usual due to inadequate surgery
   e. Cold instrumentation may give better rate of cure

9. Vocal fold scarring
   a. The CO_2 laser is effective in vaporising the scarred tissue and optimise the phonatory outcome
   b. The CO_2 laser should be used carefully in superpulse mode, with acublade, with single shot exposure to gently excise the scar to minimise deeper thermal penetration
   c. Scarring due to sulcus vergeture is less severe than sulcus vocalis and thus the CO_2 laser management gives excellent results
   d. If the loss of tissue is more than one mm after the excision, thyroplasty procedure is appropriate
   e. A good phonatory result can be achieved with injection laryngoplasty even if the phonatory gap is as much as 2 mm following excision of scar

10. Restoration of lost mesenchymal tissue: which of the following statements is true?
   a. Although stem cell technology has been successfully used, its routine use is still not well established
   b. Injectable biomaterials are currently used widely to augment the vocal fold. The fibro-elastic properties of these biomaterials give excellent results in the reconstruction of the vocal fold lamina propria
   c. Augmentation should be routinely carried out in order to optimise the phonatory outcome after a failed voice therapy regime
   d. In case of wide vocal incompetence, failure to augment may result in dysphonia plica ventricularis
   e. All of the above

Chapter 9

Human papilloma virus infections: Recurrent respiratory papillomatosis

M. Remacle and V. Oswal

1. Introduction: Human papilloma virus (HPV) infections

Various serotypes of the HPV have been implicated in the aetiology of genital and aero-digestive tract lesions, and recently, in site specific malignant oral lesions. The following paragraphs provide an up to date literature review on this important topic of HPV infections affecting the various subsites. It is important for a laryngologists to ensure that the papilloma tissues are submitted to serotyping to identify the subtypes which may have implications on screening, prevention and therapeutic management of lesions at other sites.

1.1. Genital warts

Genital (HPV) infection, mostly acquired during adolescence, is the most common sexually transmitted infection with an estimated worldwide prevalence of 9-13% and approximately 6 million people being infected each year, mostly acquired during adolescence or young adulthood.

Serotypes
HPV6 and HPV11 cause genital warts. HPV16 is usually identified in the genital tract; HPV type 16 (and to a lesser degree HPV type 18) is linked with more rare cancers, namely cancer of the vulva, vagina, penis, anus, oropharynx and larynx (Dillner *et al.*, 2007; Pandhi and Sonthalia, 2011).

1.2. Oral squamous cell carcinoma (OSCC)

While smoking and drinking are implicated as risk factors in 75% of OSCC, the aetiology in the remaining 25% (non-smokers and non-drinkers NS/ND) of OSCC remained obscure. However, in the first decade for this century, increasing number of reports have identified Human Papilloma virus infection (HPV) as a risk factor in the NS/ND group of OSCC.

Andrews *et al.* (2009) undertook a retrospective analysis of (NS/ND) OSCC patients to determine HPV infection as risk factor. Consistent detection of statistically significant HPV raised the possibility that HPV infection may play part in the development of OSCC in NS/ND.

Infection with HPV-16, is now an established risk factor for head and neck cancers (HNOSCC). Most cases involve the oropharynx.

Due to this important information, it seems that every patient of the recurrent respiratory papillomatosis (RRP) should have lesions submitted for sero-typing. Next few paragraphs provide literature review on the HPV 16 related OSCC in NS/ND patients in some detail to emphasise the importance of serotyping.

Epidemiology
HPV infection has changed the demographics of HNOSCC patients, as these patients tend to be younger, non-smokers, and non-drinkers. According to Cohen *et al.* (2009), the incidence of OSCC may be increasing among younger age groups in the

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Western Hemisphere. Oral HPV infection acquired through oro-genital contact appears to be the principal risk factor for HPV-associated oral cancers (Gillison, 2008).

Serotypes of HPV in NS/ND OSCC

The majority of NS/ND oral cancers (approximately 90%) are identified as HPV-16 positive (Gillison, 2008; Hannisdal *et al.*, 2010; Herrero, 2003).

Site Predilection

Attner *et al.* (2010) noted base of the tongue to be the subsite of predilection, whereas, Fakhry and Gillison (2006) reported lingual and palatine tonsils, as the subsites with predilection to develop OSCC in HPV-positive patients.

Clinical implications

The HPV aetiology of these tumours may have future clinical implications for the diagnosis, therapy and screening. In particular, potential role of HPV infection in transforming oral epithelium to OSCC makes a strong case for screening the oropharynx for HPV in NS/ND.

There is sufficient evidence to conclude that a diagnosis of HPV-positive HNSCC has significant prognostic implications; these patients have at least half the risk of death from HNSCC when compared with the HPV-negative patient. Furthermore, prognosis seems to be much better than for patients with non-HPV- and tobacco-related tumours (Hannisdal *et al.*, 2010, Worden and Ha 2008; Syrjanen, 2005; Torrente and Ojeda, 2007).

Prevention

Pandhi and Sonthalia (2011) note that vaccines are most effective in preventing HPV infections when given before the onset of sexual activity and provide long-term protection. Effective vaccination coverage in young adolescent females substantially reduces the incidence of the anogenital malignancy-related morbidity and mortality.

They advocate a quadrivalent vaccine Gardasil® against HPV types 6, 11, 16, and 18, recommended for use in females 9-26 years of age, for the prevention of cervical, vulvar, and vaginal cancers and intraepithelial neoplasia and condyloma acuminate. They also note the recent trend of vaccination in boys and men 9-26 years of age for the prevention of genital warts, a source of HPV16 in oro-genital contact.

Cervarix™ is a bivalent vaccine approved for the prevention of cervical cancer and precancerous lesions caused by HPV 16 and 18, in females 10-25 years. HPV vaccines are safe and efficacious against type-specific HPV-induced anogenital warts, precancerous lesions, and cervical cancer.

Laser management of oral cancer is covered in Chapter 39.

1.3. Aero-digestive lesions –recurrent respiratory papillomatosis.

Recurrent respiratory papillomatosis (RRP) is the most common benign laryngeal tumour encountered in general otolaryngological practices throughout the world (Derkay and Wiatrak, 2008). Despite its benign histology, RRP has potentially morbid consequences and is often difficult to treat because of its tendency to recur and spread throughout the respiratory tract. Long neglected from an epidemiological standpoint, recent initiatives to better understand this disease process have been launched through coordination between the Centres for Disease Control and Prevention and the American Society of Paediatric Otolaryngology. Practice Guidelines of the Recurrent Respiratory Papillomatosis Task Force have also been proposed (Derkay, 2001a). Therefore, a rather detailed account of the condition is presented in the following sections.

2. Epidemiology

Although papillomatosis occurs more frequently in lower-income house-holds, the disease is encountered in all socio-economic classes (Gallagher and Derkay, 2008).

3. Aetiology

RRP is caused by unencapsulated icosahedral capsid human papilloma virus (HPV). It shares an identical viral aetiology with genital condyloma and, in all likelihood, is transmitted at the time of birth (juvenile onset RRP) or through intimate sexual contact (adult onset RRP)(Kashima *et al.*, 1996).

4. Serotypes

The most common types are HPV6 and HPV11, while HPV16 and HPV18 are much rarer. Other types like types 13, 26, 31, 33, 39, 40 and 56 are also implemented (Draganov *et al.*, 2006; Mammas *et al.*, 2010; Muenscher *et al.*, 2009).The various types are linked both to the age group and site of predilection to disease process.

5. Incidence

Reports estimate the incidence of RRP in the United States at 4.3 per 100,000 children and 1.8 per 100,000 adults (Derkay and Wiatrak, 2008).

6. Clinical types

Two clinical types of RRP are recognised: the aggressive juvenile type (Reeves *et al.*, 2003; Ruparelia *et al.*, 2003); and the less common adult-onset type. However, the juvenile type can also occur in adults. The aggressive juvenile type usually appears in children by the second or third year of life. In adults, the age of onset is usually between 20 and 40 years.

7. Aerodigestive tract lesions

RRP appears most frequently in the larynx. However, it can also affect the entire aero-digestive tract (Reeves *et al.*, 2003; Xue and Wang, 2010).

8. Predisposition

It is apparent that there are a number of factors that may predispose a patient to the development of the disease, particularly in patients with compromised immune system (Sisk *et al.*, 2006):

- AIDS
- Immunosuppressive therapy for organ transplantation
- Congenital immunodeficiency
- The time of contamination
- The duration and degree of exposure to the virus
- Local injury
- Reflux

The inflammation induced by chronic acid exposure may result in the expression of HPV in susceptible tissues. Prompt diagnosis and effective treatment of extra-oesophageal acid reflux disease (EERD) should be considered in all patients with refractory RRP or with clinical presentation or endoscopic signs of EERD (McKenna and Brodsky, 2005).

9. Juvenile papillomatosis

9.1. Transmission of juvenile papilloma virus

A correlation between cervical HPV infection in the mother and the incidence of RRP in the child has been clearly established (Sinal and Woods, 2005; Stamataki *et al.*, 2007). Infection in children has been associated with vertical transmission during vaginal delivery from an infected mother (Derkay and Wiatrak, 2008). The incidence of transmission is greater in primipares, because of the prolonged delivery. However, although HPV has been found in the nasopharyngeal secretions of 47% of children (Sedlacek *et al.*, 1989) exposed to HPV within the genital tract, only a fraction of them develop RRP: the risk is approximately 1:400. In-utero contamination may be a possibility.

The absence of HPV (other than in the papilloma itself) in the upper aero-digestive tract of patients and caregivers is consistent with the *absence* of reported cases of horizontal transmission to siblings or other family members. These findings are also consistent with the conventional view that juvenile respiratory HPV is transmitted vertically from vaginal condylomas in the mother(Sun *et al.*, 2000).

The precise mode of transmission of HPV remains unclear. Patients with RRP are able to have healthy children regardless of the stage of the disease. Partners of RRP patients do not develop RRP. Pregnancy, however, has a negative impact on the course of RRP and local laryngeal status in patients; it is more significant in HPV type 11 associated cases since it is manifest by more rapid papilloma growth and more frequent recurrence (Gerein *et al.*, 2006).

For the potential prophylactic benefit, caesarean sections in selected high-risk expectant mothers should be considered (Kashima *et al.*, 1996). But although caesarean section may prevent the exposure of children to the HPV virus during childbirth, its effectiveness in preventing RRP is debatable and the caesarean sections itself carries an increased risk of complications (Kosko and Derkay, 1996; Larson and Derkay, 2010). To date, scientific proof is not conclusive to advocate caesarean section for mothers suffering from condylomas, because the exact mode of transmission remains unknown (Kosko and

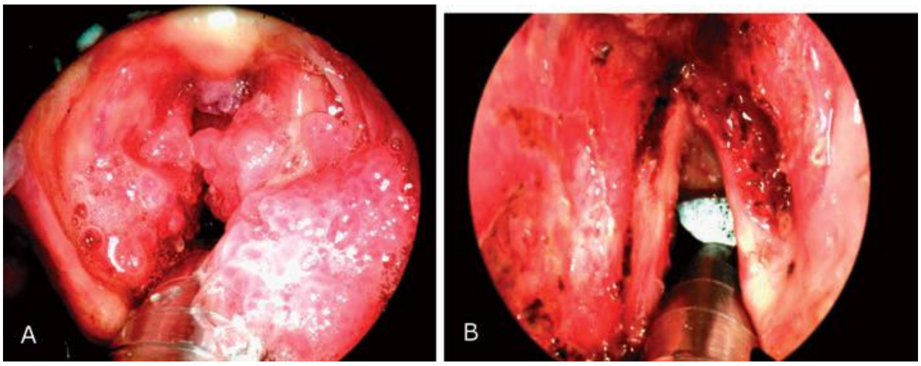

Fig. 1. A. Gross papillomatosis of the larynx; B. Post-operative view, CO_2 laser removal of gross papilloma. Note: the free edge of the vocal folds has been meticulously preserved.

Derkay, 1996). Moreover, children born following caesarean section also show RRP lesions.

10. Adult onset RRP

Human papilloma virus (HPV) infections in young adults (adult onset RRP) are among the most prevalent of the sexually transmitted diseases, with up to 75% of women in the United States acquiring genital HPV infection at some point in their lives. The adult-onset form may be caused by urogenital contact (Sinal and Woods, 2005).

11. Adult transmission

HPV infections of the genital tract are of medical and public health concern due to their propensity to lead to the development of cervical cancer, and because they can be transmitted to the respiratory tract of a newborn child, resulting in juvenile-onset recurrent respiratory papillomatosis (Kimberlin, 2004).

In all likelihood, the virus is transmitted through intimate sexual contact. The transmission risk has been assessed to be as high as 60%.

12. Pathogenesis

Taken together, RRP is a complex, multigene disease that manifests itself as a tissue and HPV-specific immune deficiency, preventing effective clearance and/or control of HPV-6 and -11 infection (Bonagura *et al.*, 2010b). Natural killer cells expressing activating receptors KIR3DS1 and KIR2DS1 (polymorphic killer cell immunoglobulin-like receptors) may be necessary to trigger an effective early immune response against HPV-infected targets to establish resistance to RRP development (Bonagura *et al.*, 2010a). Natural killer cells are dysfunctional in RRP.

HPV 6 and 11 infections could establish a tumourigenie microenvironment characterised by alteration of both innate inflammatory signals and adaptive immune responses that prevent effective T (H) 1-like response, in conjunction with altered expression of numerous genes that regulate cellular growth and differentiation (DeVoti *et al.*, 2008)

Apoptosis is an important factor in normal cellular homeostasis. Deregulation of this process, as determined by abnormal expression of anti-apoptotic factors such as survivin is thought to govern the behaviour of certain neoplasms. The mean expression of survivin, a cell cycle-regulated anti-apoptotic factor, is almost five times greater in the RRP papillomas than in normal tissue. Survivin protein is differentially expressed in the papilloma specimens, and is greatest in papillomas that undergo malignant transformation. Survivin is absent in all normal laryngeal tissue tested.(Poetker *et al.*, 2002).

Vascular endothelial growth factor-A (VEGF-A), known to play an important role in the angiogenic response essential for tumour growth in a variety of human and experimental tumours, is strongly expressed in the epithelium of squamous papillomas in RRP (Rahbar *et al.*, 2005).

Viral replication appears to observe the following sequence. Initially, there is viral colonisation of the cells of the basement membrane. This is followed by entry of the viral DNA into the cellular nucleus with production of RNA and viral proteins.

13. Histopathology

Histopathological examination shows non-keratinised stratified squamous epithelium, supported by a core of highly vascular connective tissue stroma. In addition, clinically normal surrounding tissue has also shown the presence of HPV. This observation explains the frequent local recurrence. Avoiding surgical trauma to the surrounding tissues prevents iatrogenic dissemination.

14. Clinical presentation

In children, RRP is the second most frequent cause of dysphonia, after vocal fold nodules (Derkay and Wiatrak, 2008). The RRP lesion frequently occurs at the junction between ciliated and squamous epithelia. The pedunculated mass appears clinically as finger-like projections. Typically, the colour of the lesion ranges from shades of pink to pale white (Fig. 1).

15. Clinical course

In all cases, the presenting symptom is change in voice, since glottis is the site of predilection at the junction of ciliary and squamous mucosa. The second most common symptom is stridor. Initially, stridor is inspiratory, but as the lesions grow and new lesions appear, it becomes biphasic. Less common presenting symptoms include chronic cough, recurrent pneumonia, failure to thrive, dyspnoea, dysphagia, or acute respiratory distress, especially in infants with an upper respiratory tract infection. Differential diagnoses include allergies, vocal nodule, asthma, and croup.

The pathognomonic symptomatology of RRP in children is a progressive triad: hoarseness, stridor and airway distress. The course of the disease is unpredictable (Derkay and Wiatrak, 2008). At the first attack of dyspnoea, it is not uncommon for the condition to be mistaken for asthma, laryngitis stridulosa, or bronchitis.

A case of a 24-year-old woman was recently reported with a history of human papilloma virus (HPV) type 11 since childhood, originating in the larynx and trachea, and then progressing to involve the distal pulmonary alveoli and right middle ear through the Eustachian tube and mastoid, eventually extending to involve the calvaria and scalp (Lin *et al.*, 2010).

Some 14% of paediatric cases require tracheostomy at one time or another in the course of the disease (Derkay and Darrow, 2006). Since tracheostomy promotes tracheal dissemination and colonisation around the tracheostomy, decannulation must be considered as early as possible following adequate restoration of the laryngeal airway. Extralaryngeal spread of respiratory papillomas has been identified in approximately 30% of children. The most frequent sites, in order of frequency, are: oral cavity, trachea, and bronchi (Derkay, 2001b).

16. Diagnosis

Since RRP is relatively uncommon when compared to asthma, some cases remain undiagnosed until the onset of acute dyspnoea requiring tracheostomy. In older children presenting with hoarseness, diagnosis may be possible as outpatients, with a flexible fibreoptic examination. In uncooperative and very small children, diagnostic laryngoscopy under general anaesthesia is mandatory.

Besides histological examination of biopsies, routine application of molecular techniques such as real-time polymerase chain reaction (PCR) with type-specific primers for HPV types 6, 11, 16, 18, 26, 31, and 33 for detection and analysis of HPVs in patients with RRP has diagnostic and prognostic significance. For instance, RRP runs a more aggressive clinical course when HPV-11 infection is present (Draganov *et al.*, 2006). P53 genetic mutation was associated with integration of HPV-11 in histologically malignant lesions. This association may promote a progressive genetic instability that can lead to the development and clonal expansion of malignant lesions in RRP (Rady *et al.*, 1998). But according to Go *et al.* (2003) it does not appear that p53 is a molecular marker for monitoring the transformation process. Moreover, the spontaneous transformation of RRP to squamous cell carcinoma is not characterised by a histological progression through dysplasia over time. Transformation can result in the loss of HPV expression. Thus, these cancers may be very difficult to diagnose histologically and clinically early in the course of the transformation of the disease.

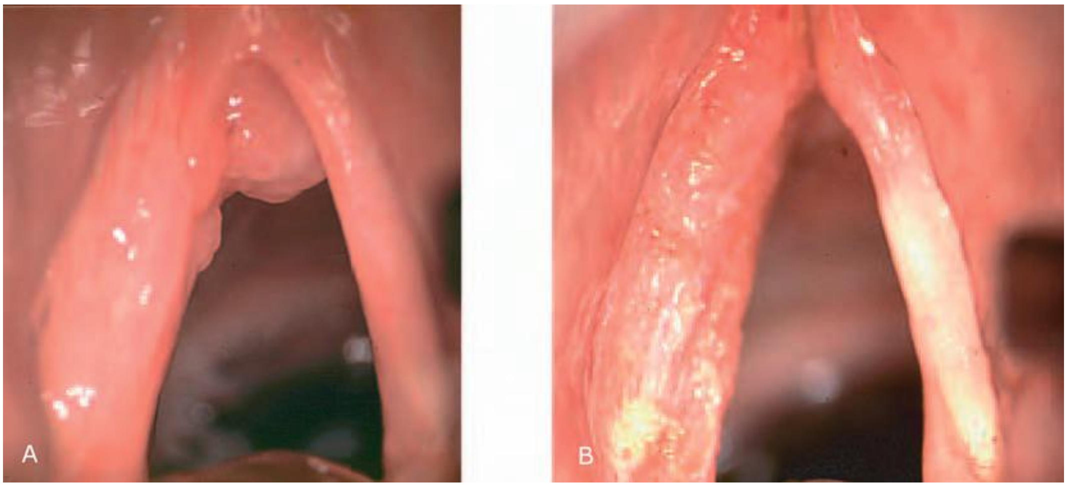

Fig. 2. A. Papilloma involving anterior commissure; B. Subtotal serial ablation may be necessary to avoid formation of web.

17. Management

RRP is a disease with a preponderance to affect the paediatric population. It has some unique features, which influence its management. Younger age at diagnosis has a twofold significance: The disease is more aggressive and there is a need for more frequent and aggressive surgical management to decrease the airway burden.

The disease can affect very young children and babies. Its natural history is unpredictable. Its severity, remission, and recurrence vary from patient to patient. Some cases may present with tracheostomy carried out at another centre. If surgical management is required for more than four times in twelve months or if there is evidence of extralaryngeal disease, consideration should be given to adjuvant medical and chemotherapeutic management.

Adjuvant therapy that has been investigated includes dietary supplements, control of reflux disease, potent antiviral and chemotherapeutic agents, and photodynamic therapy. Although several management strategies have shown promise, none of these have a proven record of offering curative potential. Furthermore, some may have serious side effects (Derkay and Wiatrak, 2008). Therefore, it is prudent that, within the context of individual practice, surgeons develop their own protocol for management. Some general observations set out later may be useful.

Most patients have a decelerating rate of debulking surgeries over time. Factors affecting the time course of RRP include: inter-surgeon variability, the extent and severity of papillomas at the time of laryngoscopy, and the use of adjuvant medical therapies (Hawkes *et al.*, 2008)

18. Initial assessment

At the first diagnostic or therapeutic intervention under general anaesthesia, a check list protocol should be followed. Unless the airway obstruction dictates immediate surgical excision, systematic examination and documentation (including negative findings) should be carried out in sequence: lips, tongue, floor of mouth, inside of cheeks, hard and soft palate, tonsillar pillars, tonsils, base of the tongue, valeculla, and lingual surface of epiglottis, oropharynx, postnasal space and hypopharynx. The attention is then directed to supraglottis, glottis and subglottic area. The presence and the extent of the ventricular, subglottic, and tracheal involvement of the disease is assessed using 0°, 30°, and 70° telescopes. A confirmatory biopsy should always be undertaken.

19. Parent counselling

Most cases of RRP will require multiple surgical interventions and therefore a close liaison between the surgeon and the parents is essential (Derkay, 1995). The purpose of the intervention is fully explained to the parents. They are made aware that, if the diagnosis is confirmed, recurring management and prolonged surveillance will be necessary because

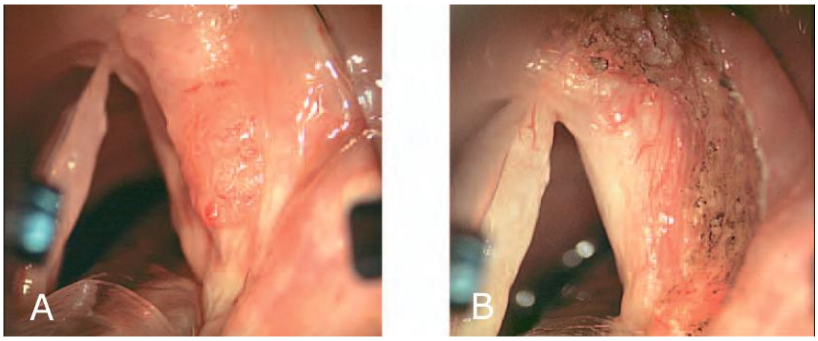

Fig. 3. A,B. Ventricular fold papilloma, away from the vocal fold. Rapid debulking can be achieved with Surgitouch™ flashscanner which ensures even distribution of energy for even vaporisation of the lesion.

of the unpredictable and protracted natural course of the disease. The possibility of tracheostomy, however remote, should be stressed, and informed written consent obtained, particularly at the initial diagnostic examination under general anaesthetic.

Recurring admissions and hoarse voice may interfere with the child's schooling. Special educational needs should be brought to the attention of the school authorities by the school medical officer. Finally, the potential sequel of web formation and its effects should be explained.

20. Patient counselling

Adult onset RRP is also a recurrent disease. It requires periodic admissions with disruptions to work schedule, recurrent hoarseness and repeated general anaesthesia. A very full discussion covering these topics along with the natural history of the disease should be discussed with the patient. Malignant transformation is a rare event and the surgeon should follow his own practicing protocol while discussing this aspect of the natural course of the disease.

21. Anaesthetic liaison

There is no particular method of anaesthesia that is superior to another in a given case. The expertise of the anaesthetist, the availability of the options, the size of the child, and the severity of the obstruction, will all influence the method. A close working protocol with the anaesthetic team will go a long way to the successful and confident management of the condition. From the surgical viewpoint, the tracheal tube should be laser resistance and as small as possible. Tracheobronchial lesions require further critical appraisal.

22. Management strategy

In the past, several techniques were used: microforceps ablation, cryotherapy (Mielhke *et al.*, 1979), and electrocautery. These techniques are now obsolete, and only used if it is not possible to use the laser or, to refer the patient to a laser centre.

The aim of management is the complete eradication of the disease whilst fully preserving the normal structures. Each therapeutic step should be as atraumatic as possible in order to avoid the spread of the disease. In patients with aggressive papillomatosis involving the anterior or posterior commissure, the procedure should be restricted to subtotal ablation consistent with restoration of adequate airway (Fig. 2). Rather than a tracheostomy, it is advisable to undertake several successive operations in a short span of time to ensure an unobstructed airway and correct phonation, whilst preserving the anatomy of the vocal fold. Multiple procedures at the glottic level can affect the voice, irrespective of the surgical tool used (van Nieuwenhuizen *et al.*, 2010; Yan *et al.*, 2007).

22.1. CO_2 laser management

The CO_2 laser has proved itself the instrument of choice (Derkay, 1995). However, since it is commonly used as free beam delivered coaxially by micromanipulator attached to the operating microscope, the target must be clearly and fully visible in the line of sight, along with normal structures in the immediate vicinity. The lesions on the undersurface of the vocal folds are thus inaccessible and therefore are not amenable for treatment with the CO_2 laser. (Ossoff *et al.*, 1991). The gross charring that was observed with first-generation CO_2 lasers no longer exists with the newer models and accessories described in Chapter 4.

For laryngeal application, the CO_2 laser is usually connected to the operating microscope via an Acuspot® micromanipulator. This accessory provides a 250-µm spot size at a focal length of 350-400 mm (Ossoff *et al.*, 1991). More recently, the development of the CO_2 laser scanning technology (Acublade®) has resulted in even more precise ablation. Using the circular scanning mode and CW setting in repeat mode with the power set at 10W per pass, it is possible to ablate a thickness of just 100µ of tissue (Remacle *et al.*, 2008). This very precise shallow ablation minimises collateral thermal damage.

When treating the lesions, it is important to take their location into account. The starting point for surgery varies from surgeon to surgeon. Some operators start in the supraglottis, others in the glottis. The logical approach would be to undertake rapid debulking so that adequate ventilation is quickly restored, irrespective of the anaesthetic method used. This step is all the more crucial with apnoeic anaesthesia or high-frequency jet ventilation (HFJV) (Grasl *et al.*, 1997).

As the surgical field approaches certain areas, the procedure needs to become more meticulous. These areas are, in order of importance: free margin of the vocal fold, anterior commissure, posterior commissure, subglottis, and crico-arytenoid joints.

The interface between the disease and the normal phonatory structures must be defined, respected and preserved, in order to ensure that the damage from the dispersion of thermal energy within the tissue is minimum.

Papillomas on the free margin of the vocal fold need careful dissection, rather than vaporisation. To ensure this, the lesion is removed using phonosurgical techniques. The focused beam is used in superpulse mode and the power is set at 2-3W. The exposure time is set at 0.1s.

For lesions at other sites, vaporisation in the continuous mode may be carried out (Fig. 3).

When dyspnoea is present, the Surgitouch™ flashscanner is used for rapid debulking. With the beam striking directly on the papilloma, away from the phonatory structures, the beam can be set at up to 30W in continuous mode, for rapid debulking to establish the airway. As the ablation approaches the laryngeal mucosal plane, the power is reduced to 4-5W. Depending on the size of the larynx and on the dimension of the operative field; the spot size of the beam can be modified.

These beam parameters as above are for guidance only. A number of variables affect the ultimate effect of the beam on the pathological (and normal) tissue. Some of the variables are: the wavelength of laser used, the beam parameters, the age and the make of the laser machine, and the experience of the surgeon. The surgical outcome is the sum total of these variables for any particular procedure.

For tracheal application, the CO_2 laser is connected to a bronchoscope (Gallivan *et al.*, 1997) via a micromanipulator. The flashscanner can also be used; the most practical ventilation is HFJV.

It may be necessary to use a fibre-delivered laser in case of office-based surgery (Chapter 59) for repeat procedures or for lesions inaccessible by direct approach, *e.g.*, the new Acupulse CO_2 wave-guide ®, KTP laser (Gallagher and Derkay, 2008), Thullium laser (Zeitels *et al.*, 2006) or 980 nm-diode laser (Newman and Anand, 2002). Use of Nd:Yag laser has also been advocated (Janda *et al.*, 2004). However, we do not recommend its use for lesions near the vocal fold because of the four-mm deep thermal effect due to scatter of the Nd:YAG laser in the free mode. The scatter is much less when used in contact mode, however, the scatter of energy may be much more extensive than that of the CO_2 laser. Argon plasma electrosurgical coagulation (Bergler *et al.*, 1998) does not offer any particular advantage over the CO_2 laser.

Intraoperative bleeding is uncommon. However, when it does occur, it can easily be controlled with a cottonoid soaked in a solution of saline and adrenaline. Smoke evacuation should be carried out with dedicated apparatus.

22.2. Angiolytic lasers: microvascular targeting

Microvascular targeting with the 585- nm pulsed dye laser (PDL) may provide a new form of therapy to control symptoms caused by RRP (Valdez *et al.*, 2001). Since the lesions involute without complete resection of the diseased epithelium, the anterior commissure can be treated to minimise the number of procedures or formation web (Hartnick *et al.*, 2007). This procedure also has a potential to be delivered on an outpatient basis with flexible fibreoptic laryngoscopes.

The PDL at 585 nm is less effective in the management of exophytic lesions because of its limited depth of penetration (approximately two mm) (Franco *et al.*, 2002). Management of RRP with angiolytic lasers is described in Chapter 60.

22.3. Microdebrider

The microdebrider has become a valuable instrument for otolaryngologists. It is now used in the larynx for treatment of recurrent respiratory papillomatosis, laryngeal stenosis, and debridement of large cancers for airway control (Schraff *et al.*, 2004; Ulualp *et al.*, 2007). But inadvertent removal of the epithelium and the lamina propria with muscle exposure can result in serious damage to the vocal folds. When using powered instrumentation the surgeon should use the utmost caution in the larynx to avoid causing debilitating injury and scar with subsequent dysphonia (Mortensen and Woo, 2009).

22.4. Postoperative management

Introduction of the CO_2 laser has transformed postoperative management, which is now usually uncomplicated. Nevertheless, arrangements should be made for expert nursing care, particularly in small babies. Humidification is extremely helpful in a smooth recovery. For detail overview of the management of general paediatric laryngology cases, see Chapter 18.

Children are usually extubated under the close supervision of the anaesthetist. During the initial procedures, which are generally more extensive, the larynx is sometimes spastic, especially in infants. This requires particular caution during extubation and careful observation during the ensuing few hours. Humidification is necessary for patient comfort. Occasionally, parenteral steroids may be required.

Discharge from hospital should be tailor-made to the home circumstances, distance involved, and the extent and duration of surgery.

22.5. Paediatric follow up

Children with RRP undergo regular follow up. This can be undertaken as outpatients in cooperative children. In others, general anaesthesia is advised. It is necessary to counsel the parents and inform them that the management of RRP is long-term with unpredictable remission and recurrence. They should be trained to watch out for any deterioration in voice, as well as for any early onset of breathlessness in the child, and to request an unscheduled appointment. Of course, lesions away from glottis will remain asymptomatic and can only be detected early with regular surveillance.

23. Multimodal management

The CO_2 laser management remains for us as the primary modality for all cases of RRP. Nevertheless, some refractory cases do require adjuvant therapy (Silver *et al.*, 2003).

At the time of writing, the long-term benefits of adjuvant therapy remain debatable. Detail discussion is beyond the scope of this book and only a brief summary of the current trend is presented below.

23.1. Adjuvant chemotherapy

23.1.1. Interferon

For a long time, Interferon (alfa-INF) seemed to be biologically the most active form of adjuvant treatment for aggressive RRP lesions (Kashima *et al.*, 1988). Its action is three-fold:

- Antiproliferative (slowing target cell growth by increasing the length of their multiplication cycle);
- Immunomodulatory (enhancing expression of cell surface antigens, resulting in increased recognition and killing of infected cells by cytotoxic leucocytes);
- Antiviral (reducing the translation of viral proteins by interfering with normal host cell translation mechanisms).

The interferon can be administered intravenously, subcutaneously, perorally, or interstitially into the affected site (Herberhold and Walther, 1995). Interferon does not cure RRP, but in a number of patients, it seems to slow down the recurrence rate. The reported results in the literature show maximal effectiveness of IFN-alpha therapy in RRP patients with HPV 6 as compared with HPV 11. The association of HPV 11 with a worse long-term response to IFN-alpha therapy and a higher incidence of malignant transformation and mortality are clinically important and indicate the necessity of HPV typing in RRP patients after the first biopsy (Gerein *et al.*, 2005b).

Several protocols have been advocated (Benjamin *et al.*, 1988). Sudden discontinuance of interferon has been known to result in a ‘rebound phenomenon', where the disease flares up. The flare up is significantly mitigated by reducing the dosage gradually over a period of several weeks, instead of suddenly discontinuing it. Irrespective of the protocol used, long-term results are not encouraging (Gerein *et al.*, 2005a). Neutralising antibodies have been found to decrease both the antiviral and the antiproliferative activity of interferon. Moreover, side-effects are not insignificant. Acute reactions include flu-like syndrome and nausea. Other side-effects include failure to thrive; raised hepatic transaminase levels; leucopoenia and spastic diplegia. It is therefore not advisable to use in children.

23.1.2. Retinoids

Retinoids, which are vitamin A analogues, have proved unsuccessful (Bell *et al.*, 1988). 13-cis retinoic acid (generic name: isotretinoin) is a powerful retinoid. It affects the process of cellular maturation. There may be other effects on RRP which are as yet not well understood. Its use is not warranted because of high toxicity and teratogenic potential.

23.1.3. Indole-3-carbino (13C)

Indole-3-carbino (13C) inhibits the development of papillomas in rabbits. This agent, which exists in large quantities in vegetables such as broccoli and artichoke, remains under active investigation (Newfield *et al.*, 1993). When 13C is broken down in the digestive process, it yields a compound (diindolylmethane, or DIM) which influences oestrogen metabolism. Normally oestrogen metabolises along one of the two very distinct pathways. Along the 16-hydroxylation pathway, it produces a metabolite that appears to facilitate tumour growth. Along the 2-hydroxylation pathway, it produces a metabolite that appears to suppress tumour growth. 13C has the ability to change the ratio of oestrogen metabolites in favour of the 2-hydroxylation pathway. In some 50-75% of patients, 13C resulted in dramatic reduction in recurrence rates requiring surgery. A recent introduction of diindolylmethane or DIM is a new product called Indolplex, renamed as Phytosob-DIM. It is said to be much more stable than the original DIM.

23.1.4. Ribavirin and Cidofovir

Cidofovir is a cytosine nucleoside analogue antiviral drug given as an adjuvant therapy in recurrent respiratory papillomatosis (RRP), (Morrison and Evans, 1993) but both Ribavirin and Cidofovir have produced inconsistent results. Nevertheless, based on the work of Snoeck (Snoeck *et al.*, 1998), in recurrent cases, cidofovir can be injected directly into the papillomatous lesions and achieve prolonged remissions.

Although the results are promising, there remains some concern about the potential carcinogenicity of cidofovir (Lott and Krakovitz, 2009; Wemer *et al.*, 2005). The percentage of patients developing a laryngeal *dysplasia* after cidifovir intralesional injection is 2.7. This percentage is concurrent with the incidence of spontaneous malignant degeneration of RRP (2-3%). It can therefore be concluded that the use of intralesional cidofovir does not increase the risk of laryngeal dysplasia (Broekema and Dikkers, 2008; Lindsay *et al.*, 2008). There have been no significant side-effects (Bielecki *et al.*, 2009).

Although intravenous administration of cidofovir can be considered in cases of lung involvement (Riviere *et al.*, 2011), side-effects have been reported following intravenous administration of cidofovir (Broekema and Dikkers, 2008). Plasma samples were collected from children and adults at 10, 45 and 60 minutes after injection to assess cidofovir plasma concentration after intralesional administration for recurrent respiratory papillomatosis of the airway.

In a study by Naiman *et al.* (2004), measurements of cidofovir were carried out using a high-performance liquid chromatographic method. A linear relationship was found between plasma concentration and dose in children (mean dose 1.2 mg/kg; mean cidofovir plasma levels 0.91 and 0.81 microg/mL), but not in adults (mean dose 0.2 mg/kg; mean plasma levels 0.21 and 0.31 microg/mL). Maximum plasma concentration averaged 34% (SD 11%) in children and 62% (SD 33%) in adults, with equivalent plasma level after intravenous infusion of the same dose. The cidofovir plasma levels were below those leading to toxicity. The levels were dose-dependent in children but not in adults. Diffusion from the injected site was greatest and unpredictable in a few adults. Cidofovir should be used at less than the recommended intravenous dose to prevent any risk of systemic toxicity.

When injections are given at longer intervals, the viral load can return to the initial values or may even be greater, and the RRP recurs (Major *et al.*, 2008).

Relapse of the disease to some extent can be expected in severe cases (El *et al.*, 2002)

Creation of RRP Serial Analysis of Gene Expression (SAGE) libraries demonstrates a broad list of genes expressed in RRP, as well as significant differences in gene expression after exposure to cidofovir, potentially allowing for a more thorough understanding of important genetic pathways in RRP treatment (Poetker *et al.*, 2008)

The role of *Acyclovir* in herpes infection is well established but its mode of action in RRP is not well understood. It is likely that its beneficial effects are related to those cases which may have concurrent (but not proven) herpes infection.

23.1.5. Methisoprinol

The use of Methisoprinol (isoprinosine), an immunostimulant, has been proposed in conjunction with the CO_2 laser (Elo and Mate, 1988).

Methotrexate, an antimetabolite used in oncology, has been used on three patients with a partial response (Avidano and Singleton, 1995).

23.1.6. Cimetidine

High dose of cimetidine is known to have immunomodulatory side effects and has been reported as a useful treatment for cutaneous warts. Harcourt *et al.* (1999) reported a case of very advanced RRP with tracheo-bronchial-pulmonary involvement, treated with adjuvant cimetidine at a dose of 40 mg/kg for four months. The patient enjoyed a remarkable improvement in her clinical condition following treatment.

23.1.7. Combination of Erlotinib and Celecoxib

Because papillomas over-express epidermal growth factor receptor, along with increased expression of cyclooxygenase-2 and prostaglandin E2 (Robinson *et al.*, 1999), it was postulated that a combination therapy of Erlotinib (an anticancer drug inhibiting tyrosin kinase) and Celecoxib (a non-steroid anti-inflammatory drug) would be effective in controlling papilloma growth. There was a striking improvement in the number and appearance of respiratory tract papillomas, with elimination of the need for repeated papilloma removal. the improvement has now been maintained for nearly two years with effective therapy (Limsukon *et al.*, 2009).

23.2. Photodynamic therapy

Photodynamic therapy has also been successfully used by some authors (Abramson *et al.*, 1988, Shikowitz, 1992). Intravenous infusion of a sensitising agent results in its absorption and selective retention by papilloma. When sensitised tissue is exposed to argon wavelength, singlet oxygen with cytotoxic property is released. It is also thought that the PDT affects the microvasculature feeding the papillomas by exhibiting anti-angiogenesis effect. As an adjuvant therapy, the PDT may have a role in the management of the RRP.

However, considerable work is being undertaken in various centres on the whole issue of the PDT as an adjunct modality for oncology and until more definite results come through, it is best that the PDT application for RRP is left with the centres actively involved in its research. Photodynamic therapy is fully discussed in Chapters 41-43.

23.3. Immunotherapy

23.3.1. Mumps vaccine

Combined with serial laser excision, locally injected mumps vaccine positively influenced induction of remission in children with RRP. The mechanisms of this effect are unclear, but the treatment is readily available, inexpensive, and has a low risk of adverse effects (Pashley, 2002).

23.3.2. Prophylactic vaccines

Effective prophylactic vaccines have been developed against HPV 6, 11, 16 and 18 (Dillner *et al.*, 2007; Vonka and Hamsikova, 2007). The potential for a quadrivalent human papilloma vaccine is being explored to reduce the incidence of this disease (Derkay and Wiatrak, 2008; Hawkes *et al.*, 2008) The quadrivalent HPV vaccine holds the most promise for the prevention of RRP by eliminating the maternal reservoir for HPV (Larson and Derkay, 2010) (see below).

23.3.3. The HPV vaccination programme

The HPV vaccination programme has brought great hope, although it is unfortunate that many current programmes only target high-risk HPV. Targeting both low- and high-risk HPV would have had additional benefits (Donne and Clarke, 2010).

Other types of vaccine are under development, viz. virus-like particles (VLP)-based vaccines, whose range of applicability will be wider than that of the present preventive vaccines, as well as vaccines that will, hopefully, be able to inhibit already progressing infection or will be utilisable in carcinoma of the cervix (Vonka and Hamsikova, 2007)

24. Surgical outcome

RRP is a recurrent disease. New lesions continue to appear in some patients, despite regular thorough clearance. The recurrence may be seen at the original site, or in a new location. Repetitive surgical intervention inevitably leads to scarring of the vocal fold due to damage to the underlying vocal ligament. Synechiae of the anterior commissure are not uncommon (Harries *et al.*, 1995). They range from blunting to a web formation. The formation and the extent of synechiae can be minimised by avoiding removal of lesions from both folds simultaneously, particularly, at, or close to anterior commissure. The denudation of the cartilage may predispose to granuloma formation. An annular vaporisation in the subglottis may induce stenosis (Crockett *et al.*, 1987).

Some workers believe that only new cases should undergo an aggressive surgical management. The goal is to excise as much of the infected tissue as possible over a few sessions, while leaving the laryngeal function intact. However, once the disease has recurred several times, it is likely that the viral DNA has infected much of the surrounding tissue already and no amount of aggressive removal will result in cure or prolonged remission. Furthermore, aggressive laser treatment for frequent recurrent disease will, in the end, results in much scarring with permanent hoarseness, without appreciable effect on the frequency of recurrence. In such cases, due consideration should be given to management with cold instrumentation, which, unlike the laser, do not have additional damaging thermal components. Newly introduced powered instruments are said to limit the scarring and perhaps, dissemination.

25. Surgery for unrelated airway conditions in patients with RRP

Boston *et al*. (2006) reported on seven children with recurrent respiratory papillomatosis who underwent major airway reconstruction. Five children had active papillomas at the time of surgery but none had worsening of their papillomas status. Significantly, two patients in remission who underwent airway reconstruction did not have recurrence of their papillomas. Thus, it seems that presence of active RRP or remission status is not a contraindication for airway surgery for any other concomitant condition.

26. Financial burden

The cost of HPV-related genital tract disease is thought to be around £31 million per annum, whereas RRP costs in the region of £4 million annually despite RRP being comparatively rare in UK (Donne and Clarke, 2010).

Chesson *et al*. (2008) estimated the health and economic benefits of preventing recurrent respiratory papillomatosis (RRP) through quadrivalent human papilloma virus (HPV) vaccination. They applied a simple mathematical model to estimate the averted costs and quality-adjusted life years (QALYs) saved by preventing RRP in children whose mothers had been vaccinated at age 12 years. Under base case assumptions, the prevention of RRP would avert an estimated US $31 (range: US $2-178) in medical costs (2006 US $) and save 0.00016 QALYs (range: 0.00001-0.00152) per 12-year-old girl vaccinated. Including the benefits of RRP reduction, the estimated cost per QALY gained by HPV vaccination was roughly 14-21% in the base case and by < 2% to > 100% in the sensitivity analyses (Chesson *et al.*, 2008).

27. Laser papilloma surgery versus other instruments

It is inevitable that the performance of laser for papilloma surgery is compared with other instrumentations, like the shaver or powered instrumentation. In this era of information technology, where the patients have an easy access to the views of the proponents of each surgical method, it is necessary that the patient risk and benefits for each method are clearly understood. However, it must be emphasised that any sophisticated technology can be quite damaging in the hands of a casual, untrained operator.

In the final analysis, the following remarks seem appropriate:

Papilloma of the aero-digestive tract is a systemic condition with predilection to respiratory epithelium, hence its nomenclature as *recurrent respiratory* papillomatosis (RRP). The recurrence of the disease is therefore not necessarily due to inadequate surgery or the type of surgical instrument used.

Removal of papillomatous tissue in the lumen of the airway may be associated with release of viable papilloma tissue which results in dissemination. The incidence of dissemination can be reduced by precision dissection with the Acublade®.

Precise removal of papillomatous tissue at the interface with the normal tissue is the most important factor which contributes to the restoration and preservation of vocal function.

Laser removal has a potential to deeper thermal damage. However, Acublade ablation allows vaporisation of just 100µ of tissue at each pass of the beam, preventing damage of the lamina propria.

Laser surgery is bloodless and thus allows precise delineation of the pathological tissue from the normal tissue.

On the other hand, if the microdebrider (shaver) is preferred, it is worth mentioning that it also has potential to damage to the lamina propria (Kirse, 2009; Ulualp *et al.*, 2007; Mortensen and Woo, 2009).

The operator strategy is a crucial factor in the overall management of the RRP. The surgical skill and the tool used to implement it, plays only a small part in the overall patient care. The patient and the parent of a child should be informed of the risks and benefits of the management strategy right at the outset. Any change in the management should be appraised fully in close consultation with the patient or the parent. The role of adjuvant therapy should be considered in all cases of refractory disease (Derkay and Wiatrak, 2008).

28. Virus-infected viable cells in the plume

Several workers have investigated the issue of viable papilloma virus in the laser plume. Presence of cells in the plume is possible due to the explosive nature of the laser ablation of tissue, releasing the cells from the peripheral layer of the crater. Kunachak *et al.* (1996) studied the potential risk of transmitting viable virus-infected cells as well as viral infectivity of laryngeal papilloma in the plume derived from a continuous mode carbon dioxide laser. Each of ten juvenile recurrent laryngeal papilloma specimens was divided into two equal parts, and one part was irradiated with a carbon dioxide laser employing a continuous mode at the power setting of 10 W with a 0.5-mm spot size and a power density of 1667 W/cm^2. The resultant laser plume was trapped and was cultured simultaneously with the other part of the specimen which served as control. All irradiated specimens yielded negative culture results while all the control counterparts revealed viable cell growth. To detect the viral infectivity, the laser plume was cultured with two separate cell systems, one was the porcine PS clone D cell line and the other, normal mucosal cells obtained from the same patient, and to control these systems both cell lines were also designed to be infected with polio virus. Both cell lines in the viral infectivity testing systems revealed no sign of viral infection. The result suggested that papilloma virus-infected cells cannot survive the continuous mode of carbon dioxide laser irradiation. They concluded that, to avoid airborne transmission of plume containing laryngeal papilloma viral-infected cells and infectious viral particles, the carbon dioxide laser parameters should be in a continuous mode with the power density ≥ 1667 W/cm^2.

Kashima *et al.* (1991) identified human papilloma virus (HPV) DNA in the plume produced during CO_2 laser vaporisation of respiratory tract papillomata. The plume produced from CO_2 vaporisation was collected on Gelfoam pledgets that were affixed to suction tips evacuating the vapour plume from the operative field. The Gelfoam pledgets were snap-frozen in liquid nitrogen, processed, and examined for HPV-6 and HPV-11DNA by a polymerase chain reaction technique. Tissue and vapour-plume specimens were collected from 22 patients undergoing CO_2 laser excision of laryngeal lesions. Seven patients had adult-onset RRP, 12 had juvenile-onset RRP, two had laryngeal carcinoma, and one had non-specific laryngitis. HPV-6 or HPV-11 was identified in 17 of 27 vapour-plume specimens from RRP and in none of three from non-RRP lesions. All but one RRP tissue specimen contained HPV-DNA, and none of the non-RRP tissues contained HPV- DNA. When HPV was present in vapour, the same HPV type was found in the corresponding tissue specimen. They state that identification of HPV-DNA in the laser plume raised concern regarding potential risks from exposure to the plume, particularly to the endoscopic surgeon and the operating team.

Hallmo and Naess (1991), reported a case of a 44-year-old laser surgeon who presented with laryngeal papillomatosis. In situ DNA hybridization of tissue from these tumours revealed human papilloma virus DNA types 6 and 11. Past history revealed that the surgeon had used laser in patients with anogenital condylomas, which are known to harbour the same viral types. They state that these findings suggest that the papilloma in the laser surgeon may have been caused by inhaled virus particles present in the laser plume.

Abramson *et al.* (1990) found that human papilloma virus DNA could not be detected in the smoke plume from vaporisation of laryngeal papillomas unless direct suction contact is made with the papilloma tissue during surgery.

Health Devices (1992) advise that ‘a frequent by-product of laser-tissue interactions, laser plume, or smoke has an acrid smell. The particulate matter may irritate the eyes, nose, and lungs and cause nausea; it is also a suspected vector for transmitting infectious materials, such as the human papilloma virus (HPV) associated with condyloma and cervical cancer.’

Thus, although the risk of contacting the viral papilloma is negligible (Calero and Brusis, 2003), it is necessary that adequate evacuation of the laser plume produced during the vaporisation of the RRP is undertaken by means of a dedicated suction unit. The risk of exposure seems to be higher in gynaecological interventions than in ENT because of the much larger tissue masses and because laser plume escapes easier into the room air when applying an open approach. For further discussion on laser plume see Chapter 3.

29. Risk and benefit issues

29.1. Potentially life-threatening disease

RRP is a progressive and life-threatening condition. Larynx is by far the most common site of predilection. Lesions start as small multimodal sessile elevations on the mucosal surfaces of the laryngeal structures. Untreated, they continue to proliferate, causing symptoms of hoarseness, dyspnoea, stridor and eventually, life-threatening airway obstruction. Intubation may not be achievable and emergency tracheostomy is necessary to restore airway.

29.2. Tracheostomy

Tracheostomy site shows predilection to new lesions, and therefore, best avoided as far as possible. Some authorities believe that involvement of tracheostomy site is an indication of an aggressive nature of the disease rather than a precipitating factor. Even when a full regression of the disease has been achieved, extubation may not be tolerated due to its dependency.

29.3. Malignant transformation

Malignant transformation can occur in adult type, the incidence of squamous cell carcinoma arising in pre-existing papilloma is stated to be in the region of 3-5% of patients. Sudden increase in the recurrence rate and vascularity are suspicious and should lead to repeated biopsies from suspect site which is usually tracheo-bronchial tree or pulmonary parenchyma. Malignant change is more common with disease caused by HPV-11 and HPV-16. Prognosis is invariably poor.

29.4. Disruption in life style

Frequent monitoring and removal of any recurrent or new lesions is required in all cases. Such management strategy is universally accepted, although it does lead to much disruption of life style. In children, there is loss of schooling due to frequent admissions. Family life is affected since parents have to take time off work. In adults with frequent hospital visits, loss of meaningful employment may be an issue.

29.5. Iatrogenic damage

Repeated removal with CO_2 laser may result in loss of tissue and healing with a scar, although such risk is now considerably lower due to improved accessories that minimise deep thermal spread of the laser energy. Some authorities prefer microdebrider in the belief that it is less traumatic, with no thermal spread. However, like any other tool, it can be equally hazardous in untrained hands.

29.6. Anterior web formation

Lesions at the anterior commissure are difficult to treat. Laser thermal damage to the integrity of the anterior commissure leads to blunting and, in severe cases, to web formation. Significant web can cause breathlessness on exertion and requires its excision with placement of stent to avoid recurrence.

29.7. Inaccessible areas

Many sessile lesions appear at the entrance of saccule. These lesions are not easily amenable to the office-based procedures and must be addressed under general anaesthesia, since they may need excision of part of the ventricular fold.

30. Summary

Recurrent Respiratory Papillomatosis is a disease of the aero-digestive tract. It is caused by the Human Papilloma Virus (HPV), which resides in the basal layer of the epithelium. The site of predilection is the larynx. The presenting symptoms vary according to the site and the severity of the lesions. They consist of hoarseness, vocal fatigue stridor, dyspnoea, breathlessness on exertion and, in severe cases, life threatening airway obstruction.

RRP has an enormous socio-economic implication on the family life. In children as well as in adults, periodic general anaesthesia is required. Fortuitously, there is a natural disease regression of juvenile type at puberty. In adults, developments in office-based technology have resulted in office-based management under topical anaesthesia, with much less morbidity.

Management of RRP with modern technology calls for a high degree of skill level. If this is lacking, or indeed if correct equipment is not available, then onward referral is a correct strategy to optimise the surgical outcome. Early referral, an awareness of the condition amongst general clinicians and establishments of specialist units have banished tracheostomy to the history books.

Recurrence may occur within a short time following surgery, or new lesions may appear at the same or different site. If recurrence is on the vocal folds, the symptoms appear early. Parents should be made aware of symptoms of early recurrence such as hoarseness, weak cry, stridor and reduced tolerance to exercise so that they seek unscheduled review appointment.

In some cases, disease may recur after decades of symptom free period. Chronicity of the disease may lead to clinical depression and helpless feeling on the part of the patient and their families. Sometimes, there is even a feeling of guilt on the part of the mother, having passed on such a devastating condition to the child. When discussing possible aetiology with the parents, particular care must be taken not to overemphasise this aspect.

Although RRP infection is thought to stem from contamination during birth through natural passage, there is no evidence that it is contagious in the usual sense of the term. In mothers with a positive history of condylomas, birth of a child by caesarean section has not prevented expression of juvenile RRP in susceptible siblings. Likewise, in an infected mother, every sibling is not automatically infected with the juvenile type. There is no evidence that papilloma virus type 6 and 11 is passed on to the sex partner, or during oral sex. No particular hygiene precautions are advocated.

It is accepted that children contract the disease from mothers who have symptomatic or asymptomatic genital HPV. The only HPV subtypes that cause RRP are HPV 6 and 11, and occasionally 16. Gardasil, a prophylactic HPV vaccine marketed by Merck is said to prevent contraction of infection. Vaccination of females under the age of ten is in progress in some countries, to prevent contraction of infection, so that, over time, new cases of RRP may not be seen when they reach childbearing age.

CO_2 laser is the most widely used laser to vaporise and excise laryngeal papillomas. Ideally, no one tool or no one approach will fit all types of lesion. It may be advisable to use microdebrider on the vocal folds to avoid repeated laser thermal damage and the laser in other areas. Refinement in laser technology has done much to minimise deep thermal spread. There is a steep learning curve in the management of these lesions in office-based environment with pulsed KTP or pulsed dye laser. An attendance at a reputable course is well worth it. Chapter 60 covers this topic in detail.

It is important to appreciate that no amount of skilful and aggressive management will prevent recurrence, since the virus resides in the epithelium and only its expression on the surface of the epithelium is amenable to treatment. In fact, aggressive management may lead to deep thermal laser damage with irreversible scarring of the vocal folds.

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MCQ – 9. Human papilloma virus infections: Recurrent respiratory papillomatosis

1. Most *common* serotype/s of HPV causing RRP is/are
   a. HPV6
   b. HPV11
   c. HPV16
   d. HPV18
   e. All of the above

2. In oral cancers
   a. HPV16 is implicated
   b. HPV 21 is implicated
   c. HPV16 is implicated
   d. HPV18 is implicated
   e. All of the above

3. The predisposing factors for RRP are
   a. Family history
   b. Contamination from ano-genital warts at the time of birth
   c. Immunodeficiency
   d. Local injury
   e. Presence of papilloma in siblings

4. In RRP, presence of the following type/s indicate predisposition to malignant transformation
   a. HPV18
   b. HPV 21
   c. HPV16
   d. HPV6
   e. All of the above

5. In the presence of active ano-genital maternal warts,
   a. Caesarean delivery averts RRP contamination and should always be advised
   b. Caesarean delivery may not always avert RRP contamination and should not be routinely advised
   c. Caesarean delivery should only be advised if any of the siblings have RRP
   d. Children born by Caesarean delivery may also get RRP lesions and therefore, should not be routinely advised

6. In paediatric population the symptom of change in voice is the leading symptom in all cases of
   a. Singers' nodules
   b. Laryngomalacia
   c. RRP
   d. Congenital unilateral vocal cord palsy
   e. Reinke's oedema

7. In RRP, stridor is
   a. Mainly inspiratory
   b. Mainly expiratory

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   c. Biphasic
   d. Initially inspiratory since glottis is the site of predilection in most cases but as the lesion progresses, it can become biphasic
   e. Due to subglottic involvement

8. Tracheostomy for RRP should be avoided because
   a. In some cases, decannulation may not be possible due to trachestomy dependency
   b. The adequate oxygen saturation can be obtained with helium / oxygen mixture
   c. Tracheostomy encourages stomal RRP
   d. Tracheostomy can lead to tracheomalacia
   e. It is better to go for a more definitive treatment in the first place.

9. In aggressive and frequently recurring lesions in children,
   a. Manual removal is appropriate
   b. High power laser controls the disease effectively
   c. Tracheostomy should be considered
   d. Adjuvant chemotherapy should be given
   e. A complete clearance should be achieved at every operation to avoid frequent recurrences

10. Repeat procedures are frequently required in RRP
    a. Because adequate clearance in not always achievable and residual disease in inevitable
    b. The virus resides in the respiratory mucosa and thus replicates, producing new lesions
    c. The course of the disease is erratic and cannot be predicted
    d. Tissues is traumatised with manipulations and the disease spreads by seeding itself

11. Extralaryngeal disease is
    a. Always present
    b. Present in 30% of cases
    c. Uncommon
    d. Mainly found in oral cavity
    e. Is responsible for recurrences in the larynx

12. If the laser is not available
    a. Diathermy should be used
    b. Manual removal should be considered
    c. The child should be considered for onward referral where laser is available
    d. Cryotherapy is a good alternative
    e. Powered instruments are the second best choice

13. A correct anaesthetic technique is
    a. Intubation anaesthesia using laser safe tube
    b. Jet ventilation
    c. High frequency jet ventilation
    d. Jet ventilation with apnoeic technique
    e. All of the above

14. In lesions of the anterior commissure webbing can be avoided
    a. By not using the laser
    b. By using the laser at the low power setting
    c. By using Intralesional adjuvant therapy
    d. By removing one side only at any one time, followed by the opposite side after healing has taken place
    e. By using small spot size and high energy to achieve vaporisation without collateral thermal damage

15. In obstructed cases, rapid debulking can *ideally* be achieved
    a. By using high power in continuous mode and a small spot size
    b. By using laser is scanner mode
    c. By using power instruments
    d. By manually removing large chunks of tumour.
    e. By doing tracheostomy first so that the anaesthetic tube is not in the way

16. Postoperative management
    a. Should be carried out in intensive care facility
    b. Parenteral steroids should be routinely given
    c. Humidification should be routinely given
    d. Antibiotics should be routinely given
    e. Antireflux medication should be routinely given

17. In adult onset papilloma
    a. The course of the disease is not so aggressive
    b. Laser management is possible as an office based procedure
    c. Malignant transformation should be suspected if the frequency of recurrence increases
    d. Malignant transformation should be suspected if vascularity of the lesions increases
    e. All of the above

Chapter 10

Voice surgery and lasers

J. Abitbol, R.T. Sataloff and P. Abitbol

1. Introduction

There have been many major advances in voice surgery since the early 1980s. Better understanding of the anatomy and physiology of phonation allowed more accurate diagnosis and outcomes assessment. Improved surgical instrumentation has resulted in surgery with greater precision. It is now possible to remove vocal fold pathology without disturbing adjacent, normal tissue. Furthermore, laser technology has complimented ‘cold’ microsurgical instrumentation for phonomicrosurgery. Management of voice disorders is accomplished most effectively through a collaborative voice care team including laryngologists, voice therapists, voice scientists, singing-voice specialists, and others.

2. Anatomy

Anatomy of the voice is not the same as the anatomy of the larynx. Practically all body systems affect the voice. In order to achieve optimal results, surgeons must be concerned with not only surgical outcome on the vibratory margin of the vocal folds, but also the patient’s use of the entire voice-producing system.

2.1. The larynx

A detailed discussion of laryngeal anatomy is beyond the scope of this chapter. However, it is helpful to think of the larynx as composed of four anatomical units: mucosa, skeleton, intrinsic muscles, and extrinsic muscles.

2.2. Anatomy of vocal folds

The vibratory margin of the vocal fold is a complex structure, consisting of five layers (Hirano, 1981). The thin, lubricated squamous epithelium covering the vocal fold forms the area of contact between the vibrating vocal folds and acts somewhat like a capsule, helping to maintain vocal fold shape. The vocal fold vibratory margin is covered with stratified squamous epithelium specialized to withstand repeated trauma, as opposed to the ciliated columnar (respiratory) epithelium that lines much of the rest of the respiratory system, airway and vocal tract. The vocal fold epithelium is connected to the superficial layer of the lamina propria by a complex basement membrane (Gray, 1997).

The lamina propria consists of three layers. The superficial layer, also known as Reinke’s space, is made up of loose fibrous components and matrix, containing very few fibroblasts. The intermediate layer consists primarily of elastic fibres and has more fibroblasts. The deep layer is composed of collagenous fibres and is rich in fibroblasts. The region of the intermediate and deep layers of the lamina propria is called the vocal ligament; it lies immediately deep to Reinke’s space. The body of the vocal fold is made up of vocalis muscle, which is a part of the medial belly of the thyroarytenoid muscle, one of the intrinsic laryngeal muscles.

Functionally, the various layers have different

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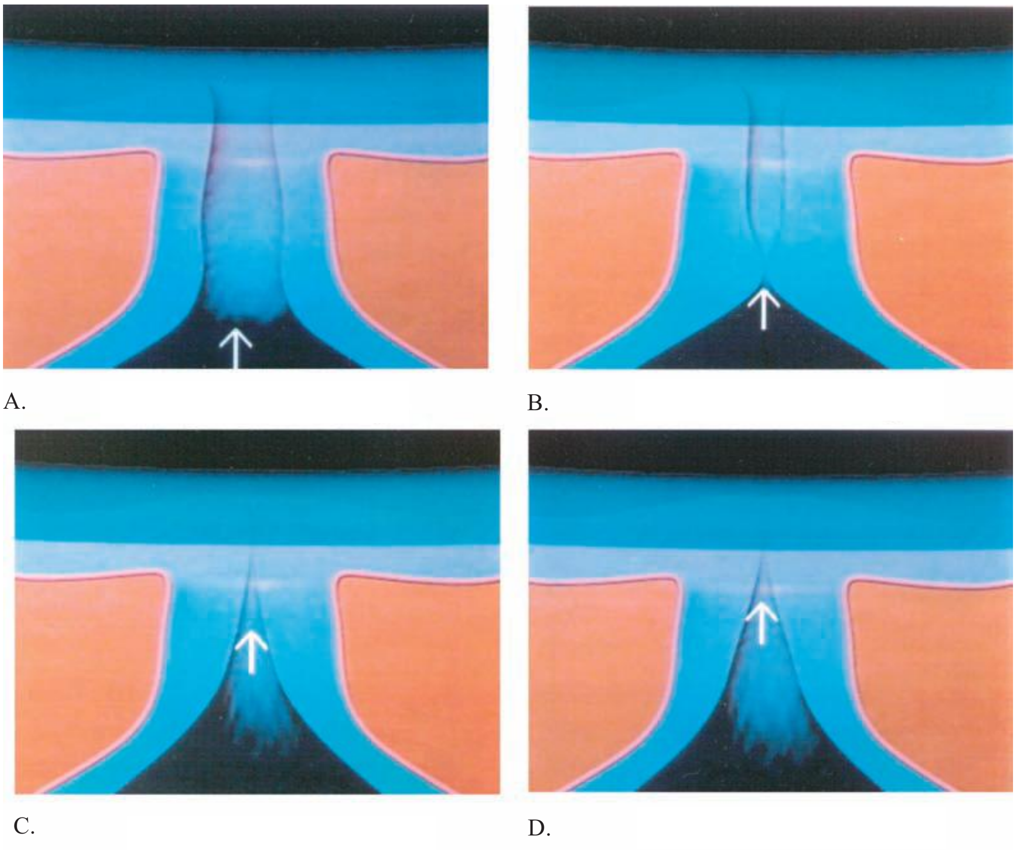

Fig. 1. Vibrations of the folds - the three edges of the lip. A. Entire free edge. B. Inferior lip. C. Middle lip. D. Superior lip.

mechanical properties. They actually act more like three layers consisting of:

a. The cover (epithelium and Reinke's space or superficial layer of the lamina propria);
b. The transition zone (intermediate and deep layers of the lamina propria); and
c. The body (vocalis muscle).

Understanding this anatomy is important because different pathologic entities involve different layers. Moreover, fibroblasts, which are largely responsible for scar formation, occur primarily in the transition zone and the body. Therefore, lesions that occur in the cover layer (such as nodules, cysts, and most polyps) should permit surgical intervention without disturbance of the intermediate and deep layers, thus, minimizing fibroblast proliferation and consequent scar formation. This is the essential principal underlying the evolution of modern voice microsurgery. Intrinsic muscles are responsible for abduction, adduction and longitudinal tension of the vocal folds. Extrinsic laryngeal musculature (strap muscles) maintains the position of the larynx in the neck, enabling the delicate intrinsic musculature to work effectively. In the trained singer, the larynx maintains a relatively constant position. Training of the intrinsic musculature results in vibratory symmetry of the vocal folds, producing regular periodicity. This contributes to what the listener perceives as a 'trained' voice. The vocal folds may be thought of as the oscillator of the vocal mechanism (Sundberg, 1977, 1981).

2.3. Surgical anatomy

The usual morphological anatomy of the vocal fold is described as having a superior and an inferior surface, with intervening free edge. However, the free edge is far from an 'edge'. The dynamic anatomy of the vocal fold shows three distinct 'borders' to the free edge, the superior, the middle and the inferior border (Fig. 1, A to D). Figure 2 A shows a small nodule arising from the inferior border, diagnosed during stroboscopic examination. Laser removal (Fig. 2, B and C) is easily accomplished, without any visible damage to the superior or middle surface (Fig. 2 D)

During surgery, when the superior border of the

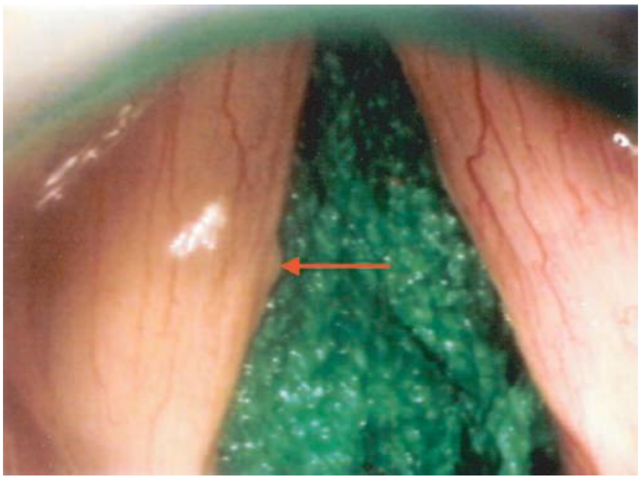

Fig. 2A. A nodule on the inferior lip of the free edge of the vocal fold – diagnosed by stroboscopic examination.

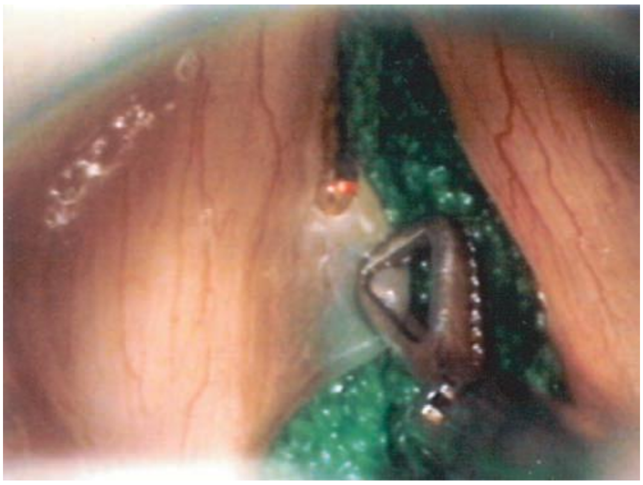

Fig. 2B. Laser removal – the beam strikes the nodule, not the vocal cord.

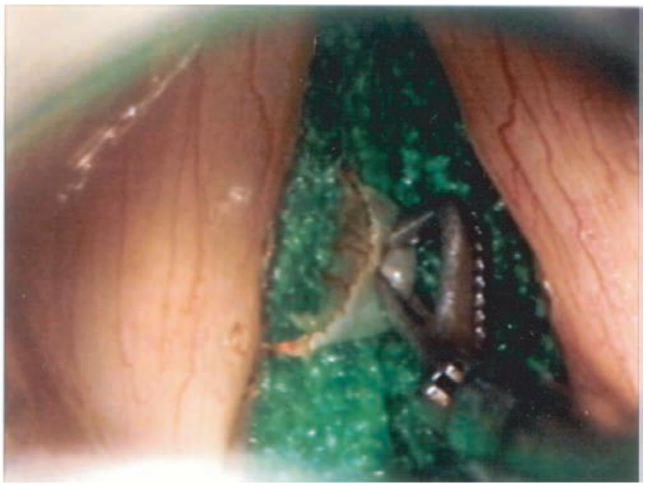

Fig. 2C. Laser removal – tangential strikes spare the free margin of the vocal cord.

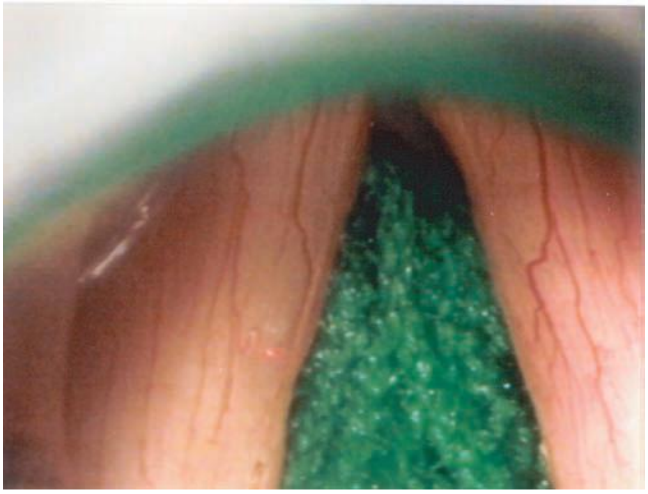

Fig. 2D. Laser removal – note the excised area on the inferior surface of the vocal fold.

free edge is surgically removed, the mechanical vibration will continue from the inferior border to the middle border, and the voice will generally recover in two to six weeks. When both the superior and the middle borders are removed simultaneously, the recovery of the vibration will usually take longer, between four and six weeks. Removal of all three borders prolongs the recovery of the vibration to eight weeks or more, and the risk of the development of a permanent scar is increased. Worse still, the scar may retract within the substance of the vocal fold, and form a sulcus, known as sulcus vocalis. In order to avoid this condition, it is advisable to leave a strip of epithelium intact.

3. Supraglottic vocal tract

The supraglottic larynx, tongue, lips, palate, pharynx, nasal cavity, and possibly the sinuses shape the sound quality produced at the level of the vocal folds by acting as a resonator chamber. Minor alterations in the configuration of these structures may produce substantial changes in voice quality. The hypernasal speech, typically associated with a cleft palate, and the hyponasal speech, characteristic of severe adenoid hypertrophy, are obvious examples. However, mild swelling from an upper respiratory tract infection or pharyngeal muscle tension produces less obvious sound alterations. These are immediately recognisable to a trained vocalist or astute critic but often elude the otolaryngologist not specialised in the care of singers and professional voice users.

4. Tracheobronchial tree, lungs, and thorax

In singing, as in speaking, the lungs supply a constant stream of air that passes between the vocal folds and provides the power for voice production. Singers are often thought of as having 'big chests'. The main difference between trained and untrained singers is not primarily increased total lung capacity, as popularly assumed. The trained singer learns to use a higher percentage of the air in the lungs for singing notes, thereby decreasing residual volume. The respiratory efficiency is thus increased (Gould and Okamura, 1973; Gould *et al.*, 1978).

5. Abdomen

The abdominal musculature is the 'support' of the singing voice, and primarily an expiratory force generator (Hixon and Hoffman, 1978). The diaphragm may also be co-activated for fine-tuning of expiratory forces and functions as an active part of the support mechanism in some singers. Proper abdominal muscle training and development are essential to safe and effective singing and professional speaking, and the physician must consider abdominal function/dysfunction when evaluating vocal impairments.

6. Musculoskeletal system

Musculoskeletal conditions and body position affect the vocal mechanism and may produce tension or impair effectiveness of the abdominal musculature, causing voice dysfunction. Careful control of muscle tension is fundamental to good vocal technique.

7. Psychological and neurological systems

The psychological constitution of the singer has a direct impact on the vocal production. Psychological phenomena are reflected through the autonomic nervous system, which controls mucosal secretions and other functions critical to voice production. The nervous system, discussed below in section 8 on Physiology, is also important for its mediation of fine muscle control. Minimal voice disturbances may occasionally be the first sign of serious neurologic disease. Psychological factors may affect voice production in other ways, and may be the primary cause of voice impairment in some cases. Psychological factors should always be considered when caring for voice professionals (Rosen and Sataloff, 1997).

8. Physiology of voice production

The physiology of voice production is exceedingly complex, and a detailed description of a voice physiology is beyond the scope of this chapter. Phonation requires interaction among the power source, oscillator, and resonators. The voice may be likened to a brass instrument such as a trumpet. Power is generated by the chest, abdomen, and back musculature producing a high-pressure air stream. The trumpeter's lips open and close against the mouthpiece producing a buzz similar to the sound produced by the vocal folds. This sound then passes through the trumpet, which has resonant characteristics that shape the sound we associate with trumpet music. The non-mouthpiece portion of a brass instrument is analogous to the supraglottic vocal tract.

9. Evaluation

Videostroboscopy is an essential part of any phonomicrosurgery planning. Not only does it show the effect of the lesion on the affected fold, but also the compensatory elements from the opposite fold and from the false fold. A weakness of the vocal fold may provoke a compensatory hypertrophy of the false vocal fold on the same side. Videostroboscopy may localise the mechanism of vibratory segment and provide important information for preservation of the remaining vibratory surface. Partial vibratory closure of the vocal fold may indicate that the lesion has extended into deeper tissue.

10. Indications for phonomicrosurgery

Laser phonomicrosurgery for benign lesions is a functional surgery; careful selection of patients is critical for a successful outcome. Particular care should be taken for voice performers, since even the most minor anatomical removal may not restore the quality of voice upon which the performers have built their careers. The extent of scarring from the excision can be controlled by meticulous attention to details, particularly in the understanding of the laser effects beyond visual control. Nevertheless, the eventual healing by scar tissue and its affect on the vibratory margin cannot be predicted with any degree of certainty. It is necessary to convey this to the patient unequivocally, in a way that he or she understands, and is in a position to give informed consent.

10.1. Preoperative voice therapy

A failure to achieve desired functional and/or anatomical improvement following a full regimen of voice therapy by a competent voice therapist is a prerequisite to any consideration to operate, conventionally or by laser. Neither is surgical method a substitute for months of voice therapy, nor is it a shortcut to restore voice.

10.2. Anaesthetic and medical risks

Patients with high risk for complications from general anaesthesia (cardiac, pulmonary, renal, metabolic, neurologic conditions) should be avoided, unless the risks are justified fully by the potential benefits. Likewise, technical problems that limit the ability to perform laryngoscopy include conditions such as arthrosis, ankylosis, short neck, prognathism, or obesity.

10.3. Timing of surgery

Phonomicrosurgery should be avoided during the pre-menstrual period, especially in patients with premenstrual hypervascularity, because of the modifications of the rheological aspect of the vocal fold, and particularly in women who have demonstrated significant Premenstrual Voice Syndrome (PMVS) (Abitbol *et al*., 1999). Speech therapy before and after phonomicrosurgery helps maintain the harmony between the multiple parameters of the voice.

11. Anaesthesia

The anaesthetic techniques used for microlaryngoscopy are adequate for phonomicrosurgery. For detailed description, please see Chapter 6 on Laser anaesthesia.

12. Characteristics of lasers suitable for phonomicrosurgery

Lasers can be used to incise, vaporise, coagulate or penetrate the vocal fold structures. The use of lasers in phonomicrosurgery was first described in the 1960's. Absorption by water yields small penetration of a laser beam. Living tissue contains a large amount of water; therefore, absorption of CO_2 laser emissions is maximal in the superficial layers of tissue. It causes a surgical defect by the evaporation of tissues fluids and subsequent burning of organic material. A small proportion of the laser light energy penetrates deeper, partly by absorption but mostly by conduction. This causes a zone of devitalised cells due to thermal damage. The thermal damage zone is proportional to the energy density and temperature of the tissue and determines the depth of scarring. Energy density depends on the time of exposure to the laser, the energy delivered, hand speed, the angle of delivery, and overall, the diameter of the impact point. Nowadays, the precision of the new generation of CO_2 laser is so accurate that the thermal damage and the scattering effect are almost negligible if excellent technique is used. If the laryngologist has the ability to obtain only one laser, it should be a CO_2 laser.

However, although the CO_2 laser is used most commonly, other wavelengths play a role. Lasers with specific vascular effects and limited surrounding tissue damage are of increasing importance. The availability of a pulsed-dye laser or pulsed-KTP laser is extremely helpful in delivering state-of-the-art laryngological care. Both pulsed-dye and pulsed-KTP lasers have advantages and disadvantages. Both can be used effectively, but the technique for their use is slightly different. The pulsed-dye laser may be slightly more prone to cause haemorrhage during a procedure than pulsed-KTP; but pulsed-KTP laser may be somewhat more likely to cause stiffness in the surrounding tissues. Either laser can be effective in expert hands. For full coverage of PDL and pulsed KTP lasers, see Chapter 60.

12.1. Nd-YAG laser

The Neodymium Yttrium-Aluminium-Garnet Laser (Nd-YAG laser) has a wavelength of 1060 nm. It is a solid state laser that emits continuous near infrared wavelengths and is usable through optical quartz fibre light guides. The Nd-YAG laser beam is transmitted through clear fluids and delivers 10-120 watts through a fibre optic channel. It produces a high degree of scatter, which results in a large spot size, small cutting effect, and substantial charring effect. The thermal effect is significant, and it is capable of coagulating vessels up to 2 mm in size. Its tissue penetrating ability is 5-7 mm. At low powers, it shrinks tissue without any vaporisation; however, if used in non-contact mode, the thermal effect could damage, destroy, or boil the lamina propria and ruin the voice. With a properly placed contact tip, the cutting effect is good, but tips must be in contact with the tissue before firing; otherwise the heat will be too high due to the scattering effect. This laser along (Sultan *et al.*, 1989), or combined with the CO_2 laser, can be used in treating obstructing malignant laryngeal lesions.

12.2. KTP (Potassium, Titanyl, Phosphate) crystal laser

The KTP/532 laser is an Nd-YAG Laser. Its potential for use in surgery increased by two important improvements: doubling of the frequency of the wavelength and point of contact. Frequency doubling offers a technique to change the output wavelength from 1060 nm (infrared) to 532 nm (green) by means of a special crystal that combines two infrared photons to one green photon. A conical sapphire at the end of an optical fibre reflects the laser beam to a sharp focal point at its tip. The temperature of the tip rises to several hundred degrees Celsius and, in contact mode, provides almost a pure cutting effect. The KTP laser is transmitted through clear fluids and structures. It does not vaporise the tissues well. It has a 200 nm spot size when delivered through fibre optic channels in endoscopes (available fibres range from 0.2-0.6 mm in diameter). It can also be used through the microscope. Perkins developed the KTP laser for otosclerosis, before it was used in the larynx (Perkins, 1980). Since 1986, KTP/532 has been used commonly in the treatment of laryngeal pathology. Its green beam can be passed through the flexible fibre optic channel of an endoscope. The indications are numerous; however, in our hands, the thermal damages seem to be more significant than that with the CO_2 laser, and we do not use it except in a pulsed mode for vascular lesions.

More recently, pulsed-KTP laser has been used for treatment of vascular lesions of the vocal fold, in a manner similar to the pulsed-dye laser (see below). The pulsed-KTP laser has a wave length of 532 nanometres. The KTP wavelength at 532 nanometre is thought by some of its proponents to be superior to the pulsed dye laser (PDL) emitting at 585 nanometre. They advocate that the 532 nanometre KTP wavelength is more strongly absorbed by oxyhaemoglobin than the 585 PDL wavelength, and is therefore less likely to cause bleeding from the vessels being treated. However, its tissue effects are different from the pulsed-dye laser, and it may be more likely to cause injury and stiffness of tissues adjacent to the blood vessels being treated. The KTP laser can be used either on an out-patient basis or in the operating room. It is delivered through a fibre. Typical settings are about 525-750 milli-joules per pulse, with a 2-Hz repetition rate using a 0.4-mm fibre, this results in affluence of about 20-80 joules/cm^2. KTP is used in a 'near touch' mode. However, much skill and experience is required to maintain a constant 'near-touch distance' from the target, to achieve maximum vascular effect while minimizing adjacent tissue response. The pulsed-KTP laser has been advocated for treatment of vascular lesions, as well as for treatment of papillomatosis and dysplasia (Zeitels *et al.*, 2006) (Chapter 60).

12.3. Dye-laser photodynamic therapy

The Argon laser emits at 632 microns. Argon lasers, or tunable dye lasers, activate hematoprophyrin derivative (HPD), which is concentrated preferentially in tumour cells (Carruth and McKenzie, 1985). Patients receive a photosensitizing agent, which is administered through an intravenous injection 24 hours before laser treatment. Only tumour cells less than 3 mm deep are destroyed, which seems a suitable modality for treating carcinoma in situ (CIS) or a T1N0 cancer. In all cases, endoscopic examination and biopsy must be done prior to developing a treatment protocol. The drugs used in photodynamic therapy can cause photosensitivity. Patients so treated must remain in darkness for 30 minutes, beginning 24 hours after an injection, to prevent exposure to natural or artificial light. If exposed, the light will be absorbed and result in thermal damage of the exposed area of the skin.

Light dosimetry is calculated, based on body surface. Before undergoing treatment with the dye laser, a biopsy must be done. First, a piece of the vocal fold is removed to diagnose the cancer. Photodynamic therapy (PDT) is performed with laryngoscopy and general anesthesia. It lasts between 20-45 minutes. Following dye laser treatment, a biopsy

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must be repeated to confirm that the margins are clear. PDT follow-up appointments are scheduled every week for two months and should be made for late in the afternoon to avoid sun irradiation.

The dye laser is potentially helpful in treating lesions of the anterior commissure, for avoiding postoperative web formation and in preserving the voice. Tunable dye lasers may prove more valuable in the future for treating selected vascular lesions of the larynx, papillomas, and other conditions. Because of the pulsed dye laser, these techniques are used less often today.

On the vocal folds, this technique is debatable particularly in the treatment of vocal fold cancer, which requires a very early diagnosis. Furthermore, due to the side effects of the PDT previously described, a minimal laser cordectomy type 1 seems to be the safer surgical option for treating T1 lesions of the vocal fold.

12.4. Pulsed dye laser

The 585 nanometre pulsed dye laser (PDL) has been used to treat vocal fold disease only recently. It was recognised by 1981 that dye lasers could be used to damage microvasculature (Anderson and Parrish, 1987). Pulsed dye lasers can be used through a flexible laryngoscope in an office setting or in the operating room. Typically, the laser is passed through a 1-mm fibre and delivers a spot size of 1-2 mm. Typical settings include up to 0.85 joules per pulse, with a 450-microsecond pulse width, a 1-Hertz repetition rate, and a fluency of 19-76 joules per square centimetre (j/cm2). Treatment is tolerated well. In addition to treating abnormal vasculature, the pulsed dye laser has been used for papilloma (Cohen *et al*., 2003; Zeitels *et al*., 2004) and dysplasia (Franco *et al*., 2003; Strong and Jako, 1971). Experience has shown that PDL is safe and effective for vascular lesions, and it also appears to be useful in treatment of carefully selected papilloma because it can avoid a general anesthesia. The patients are treated as outpatients with topical anesthesia. For recurrent laryngeal papilloma, it is one of the most useful lasers. KTP (other than pulsed KTP), Thulium: YAG laser and the CO_2 laser delivered via OmniGuide and FibreLase (Chapter 59) may cut much more deeply. It is also possible during the same procedure to inject Cidofovir with an indirect or direct endoscopic needle. However, as with any other laser, complications can occur. Haemorrhage from the vessels being treated is not rare. The prevalence of this complication can be minimised by controlling the distance of the fibre from the lesion, and by treating vascular abnormalities starting with peripheral vessels, and working toward the more ectatic portions of the lesions. However, even with the best technique bleeding can occur occasionally. The PDL is a 'no-touch' laser and has proven useful both in office and operating room settings.

12.5. Diode laser

This is a newer laser technologically with a very precise focus point. It can vaporise and cut with a minimal thermal effect. It can be guided through a fibre, and used through an endoscope to vaporise papillomas and to open recurrent glottic webs.

12.6. CO_2 laser

The carbon dioxide or CO_2 laser is a sealed gaseous laser with a mixture of CO_2, nitrogen, and helium. CO_2 lasers have a wavelength of 10,600 nm. It emits in the infrared portion of the light spectrum, which is invisible to the human eye. It requires a superimposed visible helium-neon light source to identify the invisible CO_2 laser beam path. It is highly absorbed in water and produces no backscatter caused by flash-boiling of the intracellular water and ablation of cells.

The skill of the phonosurgeon is important. He/she must aim the helium-neon light beam not on the centre of the part of the lesion to be resected, but position it so that only the edge of the beam touches the margin of the vocal fold lesion. With this technique, the thermal effect is minimal, and the healing process is rapid. Safety can be enhanced by hydrodissection. By injection of saline with a 30-gauge needle between the lesion and the vocal ligament, the dissection is simple and very effective, and a liquid barrier is placed between the laser and deeper tissue. A specimen can be obtained for histopathology.

By focusing the CO_2 laser beam, the highest energy density is expected and the cutting effect is maximised. In laryngeal surgery, the ability to cut without instrument contact, up to a distance of 400 mm through the microscope, is an important advantage of this laser. It is an aseptic technique. The combination of a coagulating effect on small blood vessels without direct contact with the vocal fold muscle (as is usually the case with cauterization) will produce precision and minimal tissue damage.

13. Instrumentation

Laser phonomicrosurgery requires dedicated instruments to allow optimum surgical conditions. A variety of laser instruments are commercially available. The illustration shows laryngoscopes and instruments developed by the authors. All laryngoscopes have channels for suction and light. The paediatric laryngoscope is suitable not only for children, but also for some female patients, and patients with restricted access to the larynx (jaw pathology, retrognathism). The long laryngoscope is used for patients with a long vocal tract. All forceps are 22 cm long and have suction for smoke removal and a unipolar coagulating system. Conventional cold instruments should also be available in case the laser malfunctions. The Zeiss or Wild operating microscope is fitted with a 350- or a 400-mm lens.

14. Micro-laryngoscopy

A small-size endotracheal tube placed in the posterior commissure allows a good exposure of most lesions. A laryngoscope needs to be placed in such a way that both the entire pathology and adjoining normal structures are clearly visible. Any distortion of the endolaryngeal structures caused by the placement of the laryngoscope should be avoided. Sometimes, when the teeth are very fragile, a dental cube is placed between the molars on both sides and a dental plate on the front teeth, thus the pressure of the laryngoscope is evenly distributed on the entire jaw. While dealing with posterior pathology such as a granuloma, or performing an arytenoidectomy, the tube is placed in the upper half-ring located on the superior blade of the valve laryngoscope. It thus passes through the anterior commisure. Ice-cold wet swabs are placed between it and the lesion.

15. Operative procedure for lesions of the fold

The surgery on the fold is carried out for a variety of reasons. The most common indication is the pathological lesion affecting voice production. However, compromised airway due to bilateral abductor paralysis will require excision of a normal

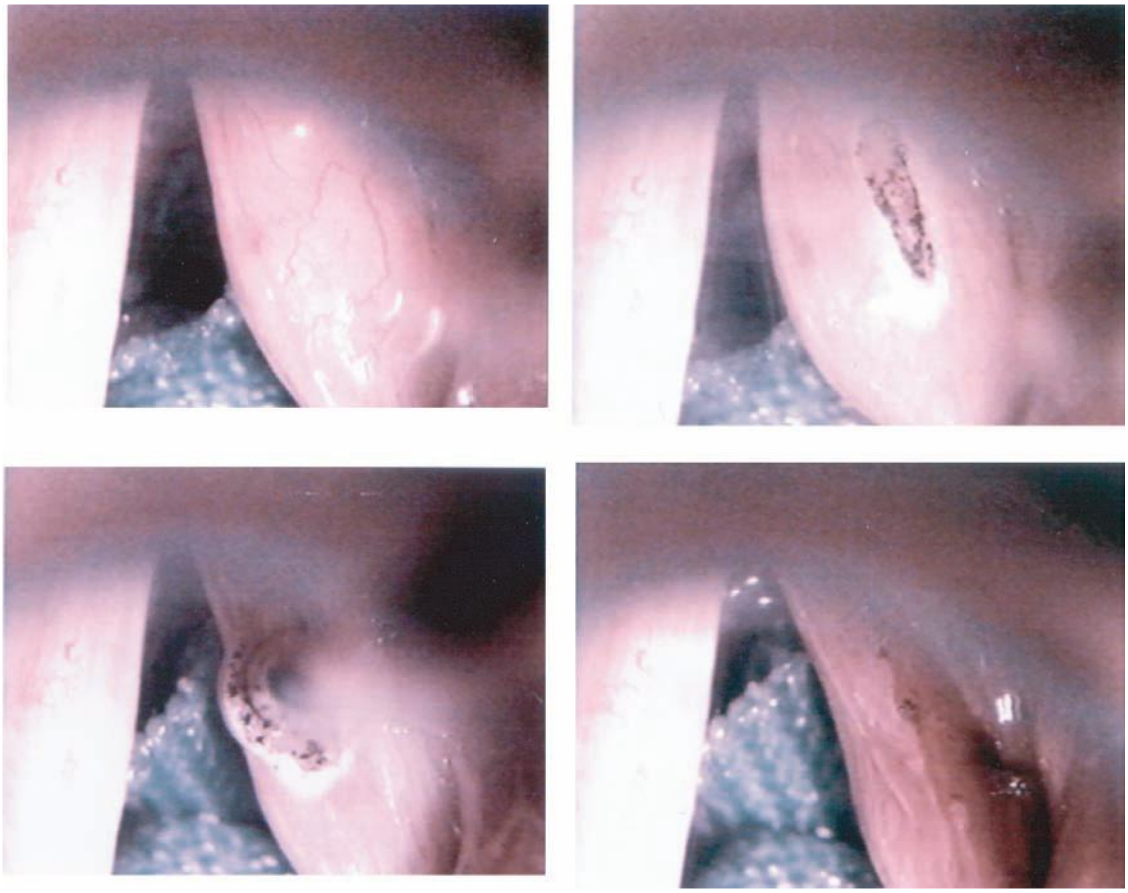

Fig. 3. Polypoid vocal fold: laser incision, suction and replacement of the flap without glue.

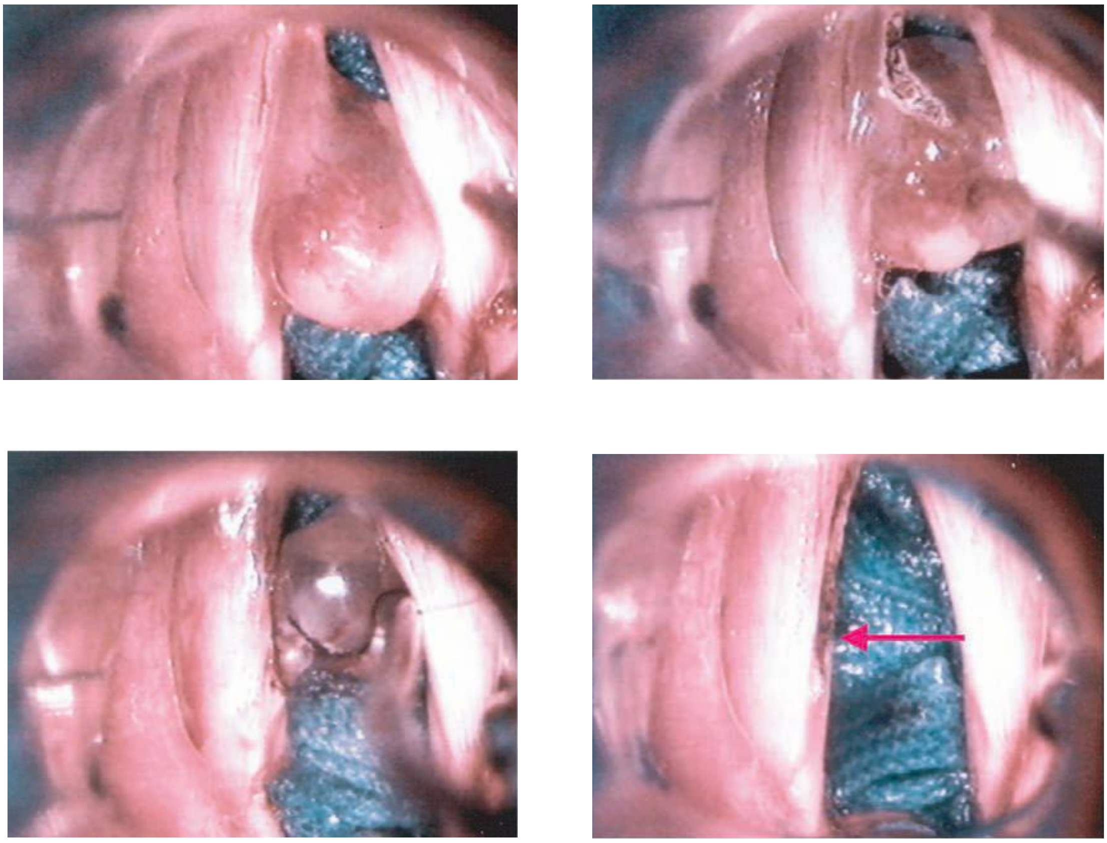

Fig. 4. Removal of polyp: tangential strikes avoid trauma to the vocal fold in final stages of laser removal.

structure such as the arytenoid or part of the vocal fold. Alteration of pitch may be sought by transsexual patients, requiring either an increase or the decrease in their pitch. Finally, malignant lesions affecting the fold require special consideration where oncological considerations override the preservation of phonatory function. Any compromise in such diagonally opposite dictum should only be undertaken with extreme caution.

16. Laser tissue ablation in phonomicrosurgery

The rate of rise in tissue temperature should be achieved as rapidly as possible. The use of superpulse mode allows high peak power with each pulsed application over a very brief period of milliseconds. There is thus an immediate temperature rise at the point of impact, resulting in instant vaporisation without charring of tissue. The power setting is usually 3 watt and the exposure time 0.05 second. The energy is applied in single shots, in repeat mode or in continuous mode, depending upon the nature of operation. Thus, while removing a lesion from the free edge of the vocal fold, it is appropriate to use single shots to limit the spread of energy to the vocal ligament, for example. On the other hand, to make the incision on the superior surface of the vocal fold to evacuate Reinke's oedema (Fig. 3), the superpulse can be used in repeat mode, and moved rapidly in the line of incision. The use of continuous mode is appropriate when dealing with a malignant lesion of the vocal fold, since the spread of energy into the deeper tissues, to a limited extent, does not worsen voice results and may help haemostasis and seal off any lymphatics. It will also reduce the operating time. The principle of superpulse is explained in Chapter 2 on Laser Biophysics.

Irrespective of the instruments used for phonomicrosurgery, in the end, the surgical technique should produce the desired effect. The choice of instrumentation simply aids the outcome, but on its own cannot replace the finesse and the expertise with which the instrument is used. The acquisition of skills required to use the laser is achieved by self-tuition, peer training and attendance at laser courses.

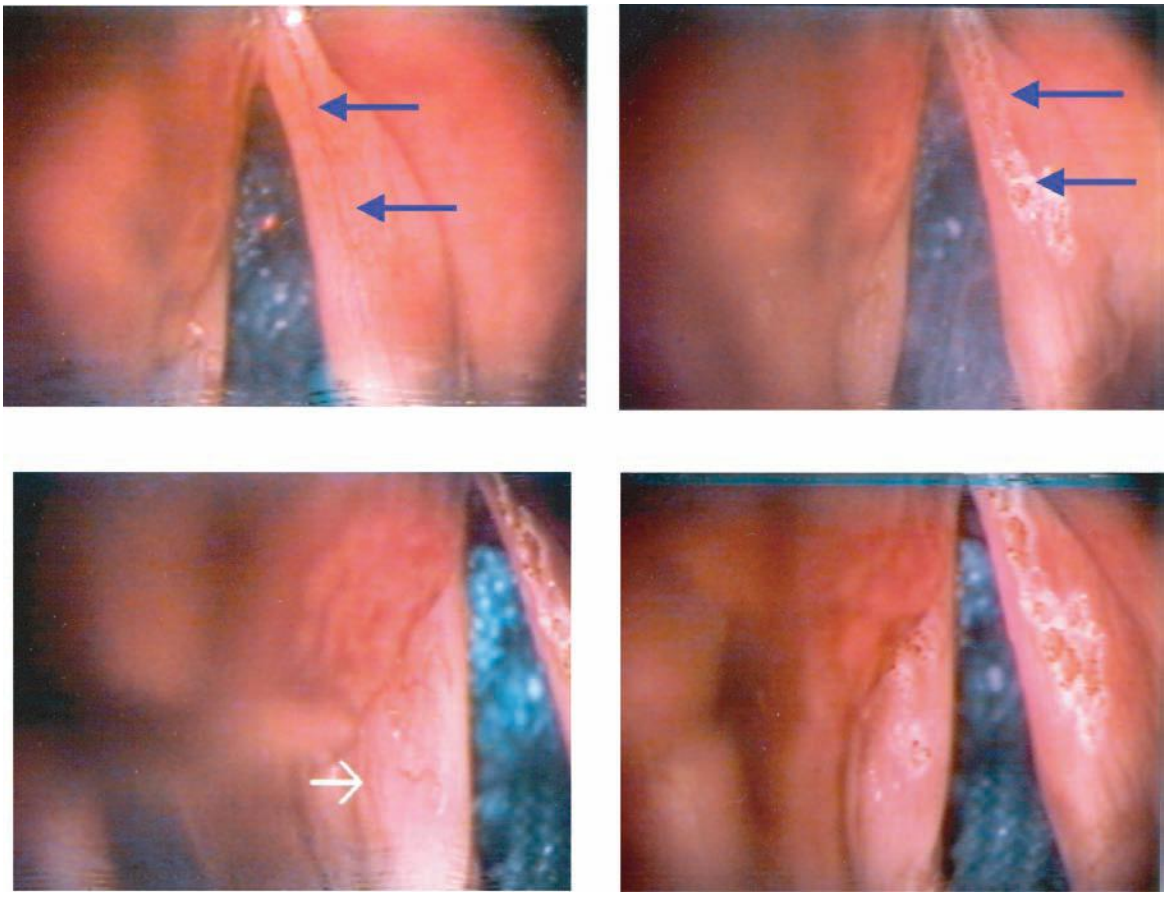

Fig. 5. Vaporisation of microvarices with defocused beam.

16.1. Tangential tissue strikes

The total spot size can further be reduced by striking the tissue tangentially whereby, only a small part of the spot falls on the tissue, the remaining part falls on an iced swab held in the proximity of the target tissue. This technique is extremely useful in the final stages of removal of pathological tissue from the free edge of the vocal fold (Fig. 4). By using only a part of the spot on the tissue, the effective spot size is thus reduced to under 100-µm.

16.2. The speed of movement of the laser beam on the tissue surface

When using the continuous or repeat mode, the slower the beam is moved on the surface, the greater is the spread of energy within the tissue. Not only the first few hundred micron layers will suffer irreversible thermal damage, but the next few hundred micron layers will be desiccated and thus will not absorb the energy which will then be conducted to even further deeper tissue. In order to limit the spread of energy within the tissue, the beam should be moved rapidly and not dwell at the same spot for any length of time, when using in the continuous or repeat modes.

16.3. Minimising vocal fold trauma during laser phonomicrosurgery

Wet cottonoids are used to wipe any tissue debris or char from the operating site. In case of any oozing of blood, the cottonoid is held on the site and the suction is applied to it rather than directly to the surface of the vocal fold. By using the cottonoids soaked in ice-cold water or saline, the ambient temperature of the fold is also reduced, thus limiting the heat spread.

16.4. Avoidance of squeals

A lesion involving both folds in the anterior third should not be removed at the same time, in order to avoid synechiae or web formation. A staged procedure is advisable. Bilateral lesions involving the middle or posterior third of the fold can be removed at the same session, without any concern of synechiae formation.

16.5. Control of bleeding and obliteration of varicose vessels

The CO_2 laser controls bleeding from blood vessels up to 0.6-mm diameter by shrivelling the tissue. Oozing can be controlled by ice-cold cottonoids held in position for a few seconds, or using swabs soaked in suitable decongestant. Any bleeding from larger vessels can be controlled by pressure or monopolar diathermy, which is incorporated in the forceps. Dilated and varicose vessels can be obliterated by defocusing the beam slightly (Fig. 5). In the defocused spot, the energy concentration is reduced, and tissue is coagulated. During arytenoidectomy or total cordectomy for malignant lesions, branches of the posterior arytenoid artery may cause substantial bleeding. It can be controlled by using pressure with wet gauze, soaked in decongestant. Only occasionally, the use of diathermy is necessary. External ligation has not been necessary in any cases operated by the authors.

17. Laser phonomicrosurgery for laryngeal lesions

Broadly, these various procedures can be grouped as follows:

- Pathological lesions:
  a. Protruding lesions, *e.g.*, a papilloma;
  b. Recessed lesions, *e.g.*, a sulcus;
  c. Flat lesions.
- Surgery for airway compromise.
- Surgery for pitch alterations.
- Excisions for malignancy.

18. Surgery for pathological lesions

18.1. Protruding lesions

The lesion is isolated by placing green square ice-cold gauze pieces, placed inferior to the lesion (Fig 6). Next, a test shot is fired on the wet gauze to ensure alignment and adequate power setting. The He-Ne beam is then aligned on the proposed incision line, on the normal mucosa, in close proximity of the lesion. An incision is made by striking the tissue with slightly overlapping shots placed close to each other. The flap is then elevated and stretched medi-

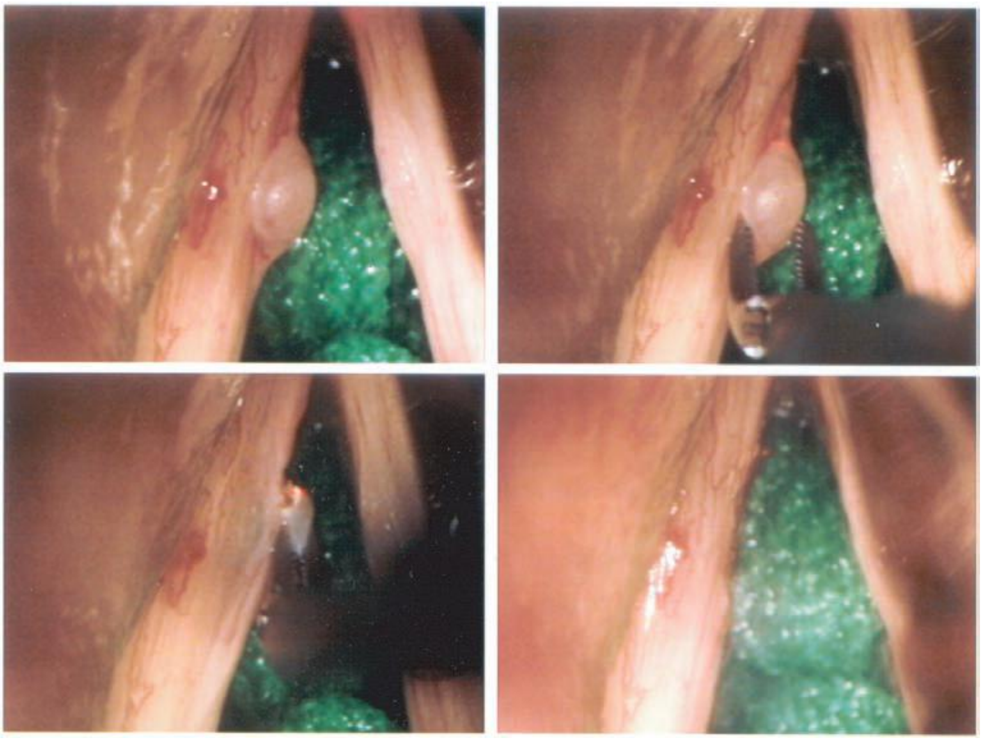

Fig. 6. Removal of nodule: wet ice-cold gauze protects the trachea and the anaesthetic tube placed in the interarytenoid area.

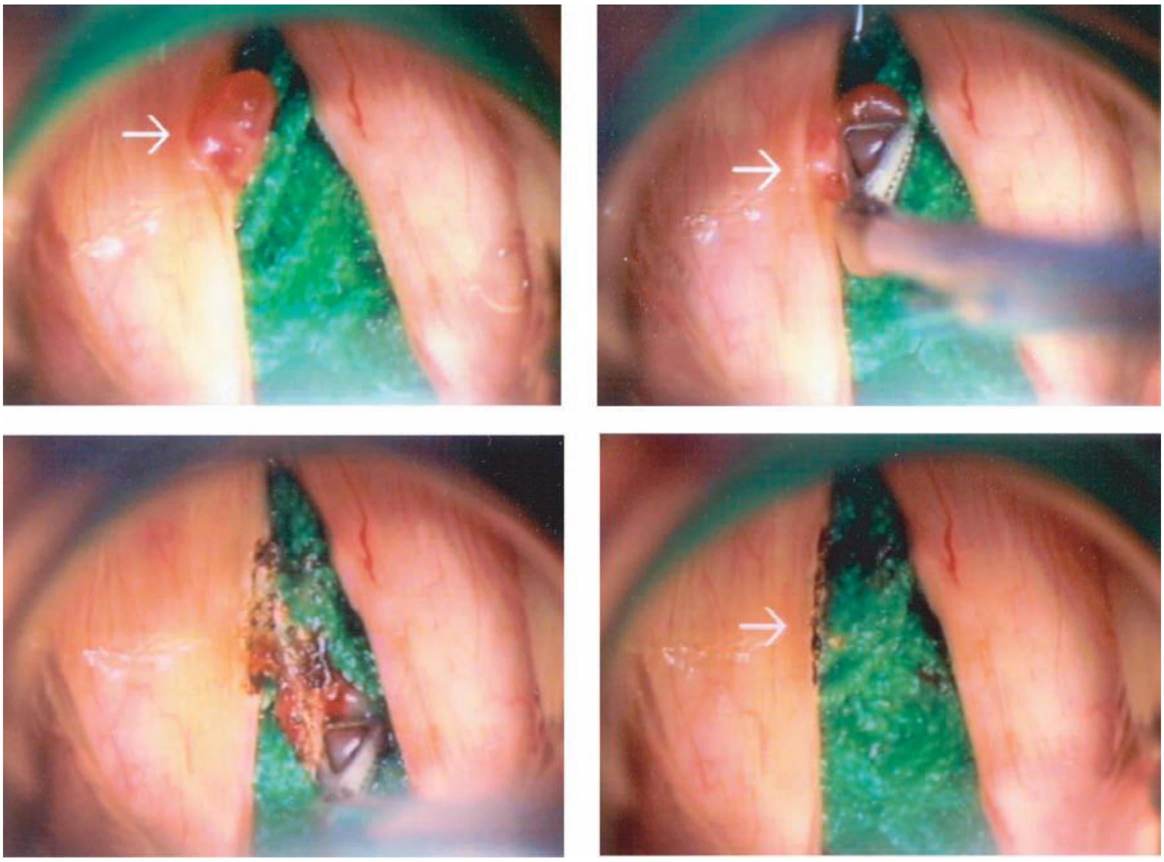

Fig. 7. Angiomatous polyp: stretching the lesion into the posterior glottic space helps laser excision.

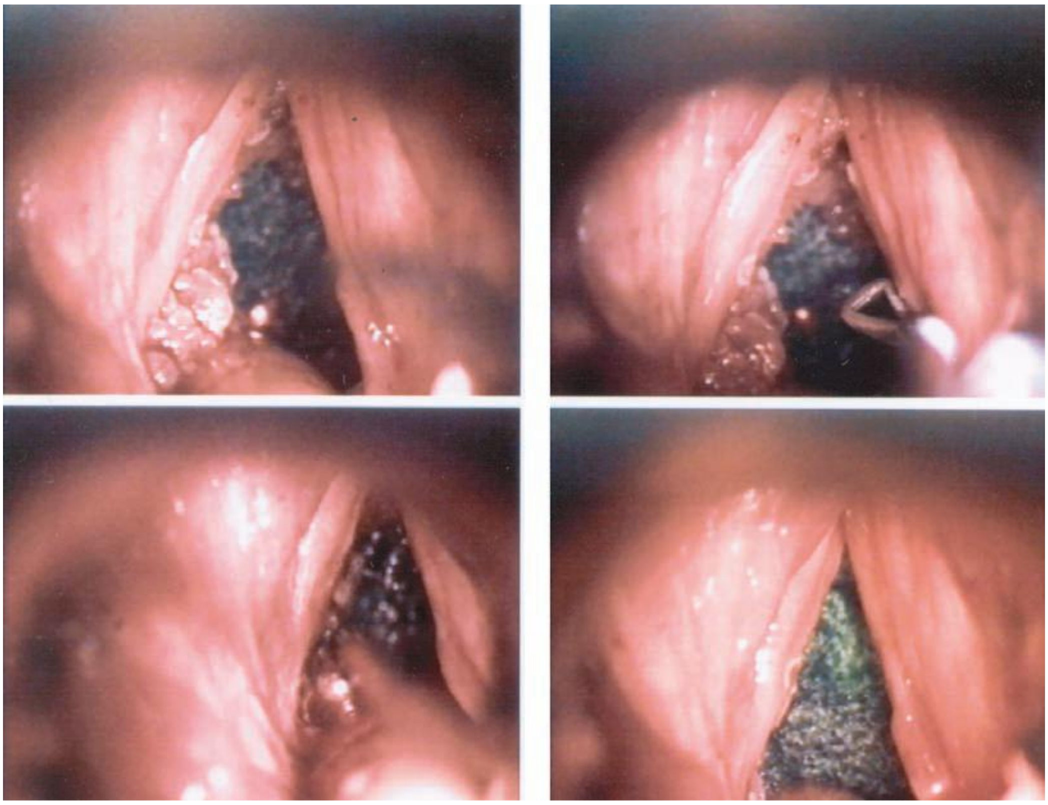

Fig. 8. Papilloma of the vocal folds – the epithelium above and under the anterior commissure is protected to avoid web formation

ally. The laser is used to vaporise stretched fibres; using single shots of 3 watts, 0.1-second duration in superpulse mode. The lesion is removed and sent for histological confirmation. The bed is examined with a 70^0 telescope, and any residual tags are vaporised with tangential strikes of the laser. Wet cottonoids are used to wipe the bed and remove any debris or charred particles, and the procedure concluded. This technique is applicable for non-vascular lesions such as nodules, papillomas, cysts, polyps, etc.

In angiomatous lesions (Fig. 7), a feeder vessel can usually be isolated. It is vaporised by a slightly defocused beam. The lesion is then removed bloodlessly as described above.

When treating lesions involving the anterior commissure, the epithelium just above and just under the anterior commissure must be protected in order to avoid potential web formation (Fig. 8). Likewise, in treating bilateral lesions, *e.g*., Reinke's oedema affecting both folds and the anterior commissure, only one side should be operated on at a time. The same principle applies to any bilateral lesions involving the anterior third of the vocal folds.

18.2. Recessed lesions, e.g., a sulcus

The surgical steps for treatment of sulcus vocalis, bowed vocal folds, scarred and atrophic vocal folds require a different strategy. For a sulcus, saline is injected underneath the lesion. A sharp incision is taken with the laser or knife and the sulcus is separated from the vocal ligament. The defect is then replaced with collagen or fat injection.

18.3. Flat lesions

Leukoplakia, intramucosal cysts and similar other lesions usually present as flat lesions. An injection of saline to make the lesion protuberant helps its removal.

19. Surgery for alteration of pitch

The vocal fold pitch is regulated by four principle parameters: the static mass, the vibratory mass, the length and tension of the vocal folds, and the subglottic pressure. It is essential that a full course of voice therapy is undertaken first and surgery performed only in refractive cases.

19.1. Increasing the pitch

Laser phonomicrosurgery can modify the vocal fold parameters. An incision is made parallel to the free edge of the vocal fold with the CO_2 laser (microspot, 1.5 watts, single shots, 0.1 sec.). The flap is raised and a few fibres of the thyro-arytenoïd muscle are removed from front to back. It is the practice of the author (JA) to inject cortisone in both folds, as in one case, atrophy was observed on the opposite side. The procedure is undertaken only on one side. If the voice is not satisfactory, the second procedure is carried out three months later. Sometimes, a web is intentionally created between the vocal folds, at the anterior commissure, to shorten the length. The epithelium of the anterior commissure is removed and both vocal folds are sutured together. Isshiki's techniques and any modifications are also satisfactory procedures if the patient accepts an open laryngeal surgery. However, the endolaryngeal laser technique is simple, allows a rapid healing and has fewer complications. Fundamental frequency before and after laser surgery will indicate if the opposite vocal fold also needs laser surgery, which is carried out not before three months.

19.2. Decreasing the pitch

Collagen, injected on one side, will increase the static vocal mass, with acceptable results. However, long term results of this simple procedure are not satisfactory, and the Isshiki procedure described in 1977 and more recently by Tucker in 1985, remains a dependable option.

20. Excisions for malignancy

The endoscopic laser management of cancer of larynx is covered elsewhere in Chapter 11.

21. Laser surgery for vocal fold immobility

Bilateral vocal fold immobility may be due to abductor paralysis or joint fixation. The laser is particularly advantageous for endoscopic arytenoidectomy. Detail description of this topic is covered in Chapter 15.

21.1. Endoscopic arytenoidectomy

An incision is made in the mucosa overlying the arytenoid cartilage from its apex to the vocal process. Whenever possible, a flap of mucosa is preserved. The medial portion of the arytenoid, or the entire arytenoid, may be removed by vaporising the cartilage or by using the laser to dissect the cartilage free. The authors generally prefer the latter technique in which the muscular and vocal processes are separated from the body of the arytenoid using the CO_2 laser. The region of the cricoarytenoid joint is exposed, and the posterior cricoarytenoid ligament is vaporised. If mucosal flaps have been raised adequately to permit exposure of the vocal process, muscular process, and posterior cricoarytenoid ligament, it is usually possible to place a right-angled instrument in the joint in order to dislocate the cartilage. It is then removed with a forceps, dividing any remaining mucosal attachment bluntly or with the laser. Vaporising the entire cartilage (or the medial three-quarters of the arytenoid cartilage) is a reasonable alternative approach. The authors also address the musculomembranous vocal fold following removal of the arytenoid cartilage. A triangular wedge of muscle is removed just lateral to the region of the vocal process to facilitate lateralisation. Alternatively, a suture is placed around the musculomembranous vocal fold through the thyroid cartilage. It is then tied either onto the cartilage through a skin incision, or over a button on the neck where it is left in place for approximately three weeks.

21.2. Bilateral ankylosis

These techniques are also suitable for the management of bilateral ankylosis, although dislocation of the joint may be much more difficult than in cases of paralysis. If dislocation is not possible, laser vaporisation of the cartilage is carried out.

22. Complications due to CO_2 laser phonomicrosurgery

22.1. The scarring of lamina propria

In surgery for small lesions confined to the epithelium, the lamina propria may suffer thermal damage. The healing with scar tissue may prevent smooth gliding of the surface leading to vocal fold vibrations seen on videostroboscopy.

23. Conclusion

In summary, a laser surgeon must first be able to perform microlaryngoscopic surgery with cold instruments. This is most important since the laser may malfunction during the surgical procedure. The efficacy of the CO_2 laser for phonomicrosurgery is now well established. However, the surgical skill, rather than the type of instrumentation more often is a decisive factor in a successful outcome.

In our experience, the Ten Commandments for success are:

1. Some patients seek consultation for hoarseness thinking that they might have cancer. If a benign lesion is diagnosed, then, any surgical management should only be undertaken with the full informed consent of the patient.
2. Optimum exposure of the vocal folds and the anterior commissure should ideally be achieved.
3. Handle the free edge of the vocal fold only if necessary, and even then, very gently.
4. Strike the laser energy only on the superior surface of the vocal fold.
5. The angle of the laser beam on the vocal fold edge must be tangential.
6. The movements of the laser beam must be smooth.
7. Protect the subglottic space with ice-cold cottonoid. These should be kept moist at all times.
8. Do not strike laser energy on charred tissue.
9. Remove charred tissue with wet cottonoids.
10. Appropriate voice rest, medical and voice therapy should be used in conjunction with both before and following laser phonomicrosurgery.

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MCQ – 10. Voice surgery and lasers

1. Vibratory margin of the vocal fold is covered with
    a. Squamous epithelium
    b. Stratified squamous epithelium
    c. Ciliary epithelium
    d. Columnar epithelium
    e. Ciliated columnar respiratory epithelium

2. Lamina Propria
    a. Contains no fibroblasts
    b. Is composed of five layers
    c. Includes squamous epithelium
    d. Is also known as ‘the cover’
    e. None of the above

3. Vocal ligament
    a. Lies deep to the Reinke’s space
    b. Composed of elastic fibres, fibroblasts and collagenous fibres
    c. Made of intermediate and deep layer of the lamina propria
    d. Along with superficial layer of vocalis muscle, forms vibratory margin
    e. Is the site for fibrotic nodules needing surgery

4. The ‘cover’
    a. Forms the vibratory margin
    b. Consists of the epithelium and Reinke’s space
    c. Consists of epithelium lining the vocal ligament
    d. Is superficial to the vocal ligament
    e. Is part of the vocal ligament

5. The free edge of the vocal fold
    a. Has one border
    b. Has two borders
    c. Has three borders
    d. Is formed by vocal ligament and the epithelium covering it
    e. Removal of a border results in prolonged recovery of voice and may lead to scar formation

6. Vocal fold trauma may be minimised during laser phonomicrosurgery
    a. By rapid continuous strikes with the laser
    b. By using laser in superpulse mode
    c. By controlling any bleeding with laser strikes to obtain better view of the pathology
    d. By using cottonoids soaked in ice-cold saline to remove char
    e. By using laser in defocused mode

7. To obtain optimum phonatory result with laser surgery, it is useful to have
    a. A selection of CO_2, Pulse dye and pulsed KTP-532 lasers to optimise surgery for a particular lesion
    b. Full exposure of the pathology and the normal vocal fold along with anterior commissure
    c. Laser on high power continuous exposure setting to remove the lesion efficiently
    d. Char-free surface for laser strikes
    e. Non-tube anaesthetic technique

8. In surgery for alteration of pitch
    a. Removal of some fibres of vocalis muscle lengthens the vocal cord and alters the pitch
    b. Scarring anterior commissure results in gap between the vocal folds and thus alters the pitch
    c. It is necessary to carry out the surgical procedure on both cords
    d. Thinning the vocal folds increases pitch, whereas thickening the folds decrease the pitch
    e. It is possible to achieve dependable results in professional voice users

Chapter 11

Lasers in the management of laryngeal malignancy

M. Remacle and A. Hantzakos

1. Endoscopic excision of laryngeal cancer: review of literature

Endoscopic excision of laryngeal cancer existed long before lasers came into use. Although reports on endoscopic excision of vocal fold cancer appeared in the latter part of the 19th century (Elsberg, 1886; Fraenkel, 1886; 1887; Schnitzler, 1888, referred to by Pratt, 1993) and the early part of the 20th century (Lynch, 1915; 1920), the technique remained rudimentary and controversial, and most surgeons rejected it. It was not until the end of the 1950s that its revival took place, due to the introduction of the microscope, which provided better illumination and magnification (Scalco *et al.*, 1960). Kleinsasser advocated endoscopic excision with the use of cold instruments and monopolar cautery (Kleinsasser, 1962; 1974; Kleinsasser *et al.*, 1988). Lillie and DeSanto (1973) reported excellent results with endoscopic transoral cordectomy, using cold instrumentation. However, the technique required a high degree of competency, and therefore remained the preserve of the few enthusiasts.

At the start of the 20th century, Jackson and Jackson (1939; 1915) used punch forceps for the resection of selected supraglottic cancers. This resection continued at intervals until serial biopsies were negative.

New and Dorton (1941) used surgical diathermy to perform transoral excision, limited only to supraglottic cancers. The poor quality of illumination limited the procedure to tumours in the suprahyoid portion of the epiglottis.

Although some workers proposed endoscopic cryotherapy for the ablation of benign and malignant lesions, it did not receive universal approval as it was cumbersome and not always successful (Miehlke *et al.*, 1979; Miller, 1973; Mulvaney and Miller, 1976).

Electrocoagulation, with reduced deep diffusion through a conductive film of liquid, or through a conductive ionised medium such as argon, has also been considered (Bergler, 2003).

During the early part of the 1970s, Strong (1974;1975) introduced the transoral carbon dioxide laser (CO_2 laser) for the excision of premalignant glottic lesions and T1 glottic carcinoma.

Clinical pioneers like Grossenbacher (1983), Motta (Motta *et al.*, 1997), Rudert (1991) and Steiner (1993) in Europe, and Vaughan (Vaughan *et al.*, 1980), Davis (1997), and Shapshay (Shapshay *et al.*, 1996) in North America were able to demonstrate that highly selected malignant lesions of the upper aero-digestive tract could be excised endoscopically with promising oncological and functional results. These authors were able to show that transoral laser surgery provides advantages relating to its haemostatic effects and precision of tissue ablation. They reported that the laser surgery was associated with minimal morbidity and good functional results. In addition, it also provides a cost-effective alternative to open surgical procedures, and to radiotherapy.

Transoral laser surgery is now a widely used surgical approach for small glottic and supraglottic carcinoma (Ambrosch, 2007; Eckel *et al.*, 2000; Rodrigo *et al.*, 2008). Successful treatment of stage

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II through to stage IV lesions of the glottic and supraglottic larynx, and oro- and hypopharynx have also been frequently reported in the literature (Eckel *et al.*, 2001; Steiner *et al.*, 2003; Vilaseca *et al.*, 2010; Werner *et al.*, 2002).

2. Endoscopic laser excision of laryngeal cancer

Cancer of the larynx involves a number of anatomical sites. The natural history, access to the lesion, and incidence of secondary metastasis are vastly different for each location, and no single management strategy is universally applicable.

2.1. Glottic cancer

There are consistent reports in the literature to demonstrate that the transoral laser management of Tis, T1 and some early T2 lesions is a viable option. Nevertheless, comparison with established conventional methods is inevitable, and, necessary. However, valid comparison is only possible if some form of standardisation is introduced.

The Nomenclature Committee of the European Laryngological Society has proposed a classification for the endoscopic excision of glottic cancer, which is described later in this chapter (Remacle *et al.*, 2000). It has received acceptance not only in Europe but also in the United States. However, the initial classification did not propose any specific nomenclature for lesions originating in the anterior commissure. To resolve this problem, a new cordectomy category, encompassing the anterior commissure and the anterior part of both vocal fold – *type VI cordectomy* – was proposed by the same committee (Remacle *et al.*, 2007).

The basis for comparison of *voice quality* following each treatment modality still remains a matter for debate (Goor *et al.*, 2007; Kennedy *et al.*, 2007; Nunez *et al.*, 2008).

While there is some unanimity regarding the transoral laser management of T1 and T2 lesions, a great deal of controversy exists for laser usage for the more advanced T3 and T4 glottic lesions (Motta *et al.*, 1997). Similarly, endoscopic laser management of supraglottic (Rodrigo *et al.*, 2008) and hypopharyngeal cancer (Caballero *et al.*, 2008; Vilaseca *et al.*, 2004) is not universally accepted as the preferred option.

2.2. Supraglottic cancer

The first report of laser treatment for supraglottic cancer appeared in 1978 (Vaughan *et al.*, 1978). This work was followed by that of Davis (Davis *et al.*, 1983) and Zeitels (Zeitels *et al.*, 1994) in the USA and by Eckel (1997), Rudert and Werner (1995) and Steiner (1993) in Europe.

Laser-assisted surgery for supraglottic carcinoma now plays a prominent role (Peretti *et al.*, 2010; Remacle *et al.*, 2009b; Rodrigo *et al.*, 2008). This is mainly due to the consistently better functional results compared to open partial resections. The main advantage of transoral laser microsurgery is that the resection can be tailored to the extent of the tumour. As in the case of the glottic tumours, ELS has recently proposed a classification for the endoscopic excision of supraglottic lesion (Remacle *et al.*, 2009a).

2.3. Hypopharyngeal cancer

Steiner (1994b), Rudert (1991) and Zeitels (Zeitels *et al.*, 1994) were among the first to advocate the management of hypopharyngeal cancer with laser-assisted endoscopy. Laser assisted surgery for hypopharyngeal cancer is presently accepted as a valid *technique* (Bernal-Sprekelsen *et al.*, 2004; Steiner *et al.*, 2001; Vilaseca *et al.*, 2004), even for salvage surgical therapy (Grant *et al.*, 2008) but requires a careful selection mainly for lesions developed in the *lateral* pharyngeal wall, with possible extension to the neck through the pharyngeal constrictor muscle (Vilaseca-Gonzalez *et al.*, 2003).

3. The role of lasers in the endoscopic management of cancer of the larynx

Jako (1972) connected the CO_2 laser to the operating microscope, and modified the endoscopic technique into an easier and quicker procedure with the laser. Since the first publication by Strong (1974), the laser, and more particularly the CO_2 laser, has gained widespread acceptance throughout the world.

3.1. Terminology

Although the terms ‘laser endoscopic surgery’ or ‘transoral laser microsurgery (TLM)’ are loosely used to distinguish the procedure from conventional microsurgery, the laser modality can be correctly described as *'laser-assisted endoscopic surgery via suspension laryngoscopy under general anaesthesia'*. However, the terms 'laser endoscopic surgery' or even more frequently 'TLM' remains in general use in order to distinguish it from conventional microsurgery.

3.2. *Advantages of laser instrumentation*

If the lesion is deemed suitable for endoscopic management, then the use of the laser offers considerable advantages over conventional cold surgical instruments. Several attributes of the CO_2 laser are useful:

- The micromanipulator coaxial delivery system attached to the microscope provides a magnified, unobstructed view of the lesion, without a carrier handle.
- There is adequate intraoperative haemostasis during the excision of most lesions.
- The thermal damage zone with Acuspot® attachment is very shallow and does not interfere with assessment of margin for histological clearance (Remacle *et al.*, 1997). This is even more true since the introduction of the CO_2 laser scanning technology (Acublade®, Lumenis, Santa Clara, CA) (Remacle *et al.*, 2005; Remacle *et al.*, 2008).

The Acublade® scanner system consists of computer-guided rotating mirrors which makes the beam to sweep the surface of the target rapidly. The beam can sweep the target as a straight, or a right- or a left-curved incision line. Various lengths (~ 0.5 to 3.5 mm) and penetration depths (~ 0.2 to 2 mm) are programmable. The curvature is similar to the one which results when Bouchayer microscissors are used.

The software-calculated penetration depth is based on the average absorption of the CO_2 laser by soft tissues *in situ*. Depending on the setting of length of incision and penetration, the software calculates the required power and pulse duration for the single pulse mode. Pulsed and continuous modes are available. The Acublade® can be used either with an operating microscope or with a hand-held device. If the operating microscope is used, the beam can be adjusted to strike to the left or to the right of the midline by rotating the scanner, connected between the laser-arm and the operating microscope with an electrical motor and controlled with a joystick. Since the line is made by a series of spots in rapid succession, the width of the line is the same as the diameter of each spot. For example, the width of the line with an objective of 400 mm is also 250 um, same as that of a diameter of each spot struck in isolation with an objective of 400 mm.

This feature makes the Acublade® a very effective tool when *macroscopic* vaporisation of a large volume of the target tissue is required. A 'shaving' effect of approximately 100 microns deep is achieved during each beam pass with very little thermal penetration. The usual shape chosen for the surface vaporisation is a circular pattern.

There is very little postoperative oedema and, therefore, tracheostomy is not necessary. Ablation in the vicinity of the cartilage or even *on* the surface of the cartilage does not result in thermal perichondritis or necrosis. In addition, there is also a *perceived* benefit: small blood vessels and lymphatics are sealed off, thus minimising any metastatic spread during surgery.

The lack of significant postoperative oedema following surgery results in early return of swallowing, in some cases by the next day. In-patient stay is relatively short. The overall duration of treatment is, of course, shorter than that of radiotherapy. When endoscopic surgery is indicated, laser surgery provides a viable option since the cure rate for both laser surgery and radiotherapy is, at the very least, comparable (Higgins *et al.*, 2009; Thurnher *et al.*, 2008). Furthermore, the morbidity is much less. Thus, the laser endoscopic management for indicated cases is truly cost effective (Phillips *et al.*, 2009; Schrijvers *et al.*, 2009).

3.3. *The choice of laser*

The CO_2 laser is, by far, the laser of choice for most surgeons. In cancer surgery, the view of the lesion is excellent since the beam does not require a carrying handle. Some workers prefer flexible hollow waveguides for delivery of the energy to lesions extending out of the line of beam path, since the waveguides allow the beam to be angled. However, the waveguide is much thicker than the optical fibre, the angulation is limited, and there is significant loss of power during transmission. Recently introduced waveguides seem to overcome these limitations. Chapter 59 provides further coverage on recent advances in the designs and clinical use of these waveguides.

Pluznikov and Konoplev (1994) advocate the neodymium:yttrium-aluminium-garnet (Nd:YAG) laser. Other workers have used the potassium titanyl phosphate (KTP) laser (Koufman, 2007; Zeitels *et al.*, 2006a), the diode laser (Ferri and Armato, 2008) and the Thullium laser (Koufman *et al.*, 2007; Zeitels *et al.*, 2006b). Pulse-dye laser (PDL) has been used recently in selected cases and seems to induce minor thermal effect on the superficial lamina propria (SLP), thus resulting in a superior phonatory outcome (Ayala *et al.*, 2007; Zeitels *et al.*, 2008).

The laser has been used in conjunction with photodynamic therapy (PDT) for achieving long term results (Franco Jr., 2007). PDT is efficient in small and superficial lesions (Rigual *et al.*, 2009). This is also an option for patients unsuitable for other treatments (Lorenz and Maier, 2009). However, the photosenstivity of the skin with current sensitisers lasts for at least six weeks and therefore, the patients need to avoid direct sunlight and bright indoor light.

3.4. Surgical instrumentation

A bivalve supraglottiscope (Eckel and Remacle M, 2010) is useful for surgery of the glottis, and is indispensable for surgery of the supraglottis and hypopharynx. Sturdy suction-based grasping forceps are necessary for reduction of the bulk in advanced tumours. Some tumours may be unusually vascular and suction coagulator should be available for haemostasis.

4. Use of laparoscopic surgical instruments

New reports from Japan introduce the use of laparoscopic surgical instruments for *en bloc* removal of supraglottic and hypopharyngeal cancers (Shiotani, 2010). Shiotani *et al.* used a distending laryngoscope with rigid videoendoscopic and laparoscopic surgical instruments. The authors claim that this surgical environment provided a wide view of the operative field, facilitating bimanual manipulation with laparoscopic surgical instruments, and enabled them to perform en bloc transoral resection. In a cohort of 21 cases with T1, T2, and selected T3 supraglottic and hypopharyngeal cancer and a minimum follow-up period of one year (average, 33 months; range, 15 to 56 months), the three-year disease-specific survival rate, and the laryngeal preservation rates were each 95%.

5. Selection of patients

5.1. Acutely obstructed patient

For acutely obstructed patients, debulking can be undertaken with the laser in order to avoid tracheostomy (Bradley, 1999). However, management of such patients requires an extreme degree of expertise by the whole laser team. The procedure is described later in this chapter under paragraph 28. Also, See Chapter 17 for further reading.

5.2. Elective surgery for laryngeal malignancy

For elective surgery, the following considerations apply.

5.3. Patient counselling

It is important that the patients and their relatives understand the options available for the management of what is *potentially* a fatal condition. In this respect, the surgeon should know the published cure rates for the various modalities, and how they compare with his *own* results.

This is particularly true in this era of the Internet, with access to various medical literature in the public domain (Evrard *et al.*, 2009). A clear-cut mission statement for each case, based on a thorough investigation and examination, will go a long way to achieve patient confidence and acceptable laser results, compared to conventional management.

5.4. Age

Laser-assisted microsurgery for laryngeal malignancy is *not* contraindicated in the older patients (Fontes *et al.*, 2001). On the contrary, it provides a viable alternative, avoiding a protracted course of radiotherapy which can be challenging because of the patient's failing general health, cardiac or pulmonary condition, etc. However, an endoscopic laser procedure for malignancy is usually a lengthy procedure, and the patient's general condition to withstand it should be carefully assessed. Adequate high frequency ventilation can prove difficult in patients with chronic obstructive airway disease. In such cases, intubation anaesthesia is obligatory. In young patients (under 40 years of age), radiotherapy is not an option because of the potential for radiation-induced carcinoma in later life. Laser endoscopic surgery is therefore a viable option in this age group.

5.5. Unimpeded access to the lesion

The most important single requirement is wide exposure of the lesion and the surrounding 'normal tissue'. If adequate laryngeal exposure cannot be obtained for whatever reason, then endoscopic excision, with laser or otherwise, cannot be accomplished. Difficult or inadequate laryngoscopy due to cervical spondylosis, full denture, temporo-mandibular ankylosis, etc., is contraindication to endoscopic surgical management (Bergler *et al.*, 1997).

5.6. Anaesthesia for cancer of larynx

While it is possible to ventilate most patients with laryngeal tumours with as little as a four-mm airway, it is necessary to ensure that, irrespective of the size of the tumour, the patient can be intubated with a large-sized tube to allow adequate gas exchange. It is necessary to stress that the ultimate choice of the anaesthetic technique is a matter for the anaesthetist, albeit after full discussion with the laser surgeon. The detailed anaesthetic technique is discussed in Chapter 6.

6. Endoscopic excision of the tumour

Another important factor for a successful endoscopic laser excision is the size of the lesion (Vilaseca *et al.*, 2010). The anatomical site is also important since *adequate* access may not be easy (Pearson and Salassa, 2003). Subglottic lesions are most difficult for endoscopic laser surgery (Remacle *et al.*, 2000).

Two different methods are followed for endoscopic removal of the tumour. The first method calls for the conventional *en bloc* removal and submission to histological examination (Remacle *et al.*, 2009b; Thumfart and Eckel, 1990). The second method involves layered excision by slicing through the tumour (Rudert and Werner, 1994; Steiner, 1994a).

6.1. Endoscopic excision of the T1/T2 tumour

Due to their size, the whole of T1/T2 tumour with clinically normal surrounding tissue can be endoscopically accessed for laser excision. In common with some workers (Eckel and Thumfart, 1992; Thumfart and Eckel, 1990), the authors advocate *en bloc* removal of the tumour as in the open surgery. The preoperative assessment of the extent of the disease determines the limits of the excision. The operative specimen is correctly oriented and pinned on a block of cork for histopathological examination.

Some workers (Rudert and Werner, 1994; Steiner, 1994a) prefer layered excision. The principle is based on minimising ablation and preserving the integrity of the function. Thus, the tissue is removed sparingly and in layers by slicing through the tumour. Advocates of this technique believe that the current operating microscope ensures gross differentiation between the pathological and the normal tissue. The tumour is removed in one or several fragments, sometimes even in several stages by planned re-admissions. The various segments are displayed as precisely as possible on a strip of cork.

In the authors' opinion, the layered technique puts the pathologist at a disadvantage. In most cases, the operating surgeon has a better overall view of the normal anatomical relationship with the abnormal pathology. He/she is therefore in a better position to decide on the removal of the whole specimen, with preservation of the normal anatomical structures.

6.2. Endoscopic excision of the T3/T4 tumour

The authors believe that the surgeons who remove large T3 or T4 tumours endoscopically are obliged to follow the 'layer method' because *en bloc* removal has physical limitations. The whole of the tumour just cannot fit into the lumen of the laryngoscope for its *en bloc* removal (Remacle *et al.*, 2009b).

7. Histopathological examination

The assessment of endoscopically excised CO_2 laser-assisted specimens does not call for a great deal of expertise on the part of the trained pathologist (Lawson *et al.*, 1997). The thermal energy in the laser surgery 'shrivels' the tissue (Fig. 1). The normal tissue thus appears much closer to the pathological tissue despite a good clear margin being apparent during excision. The histology of laser-excised tissue has certain peculiarities which are not seen after cold surgical excision. The layer deep to the pathological tissue shows thermal damage and charring. This layer is then followed by the normal histology of the anatomical structure from which the tumour has been excised.

In order to determine the clearance, particularly with the excision of T1 tumours in the anterior third of the cord where the specimen is very small, it is

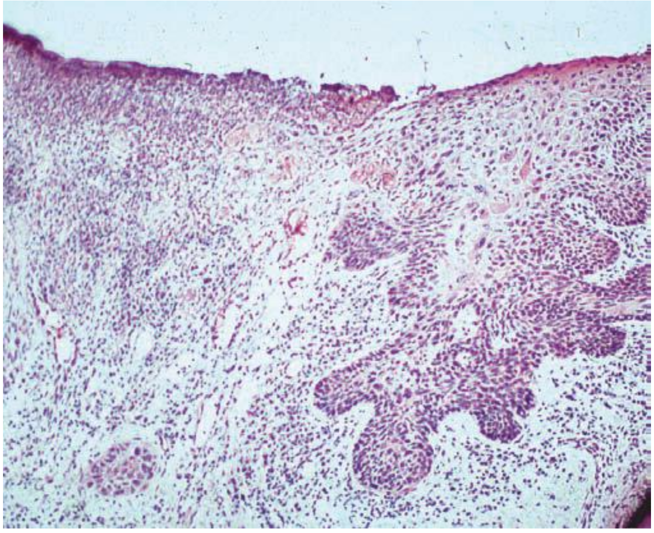


Fig. 1. Histological assessment (hematoxylin-eosin stain). Microinvasive carcinoma. The coagulation is around 50-μm deep and does not interfere with accurate assessment of clearance.

necessary to minimise the thermal damage zone. The latest micromanipulators and the recent refinements in the CO_2 beam, such as the Pulser, ensure that the coagulation along the margin of the excised specimen does not usually exceed 100 μm (Remacle *et al.*, 2008).

The thermal damage zone can be further minimised to about 50 μm by using the superpulse mode. Clearance is confirmed when tumour-free tissue is identifiable in areas not affected by the effects of laser usage (charring, coagulation) (Remacle *et al.*, 2002).

7.1. Frozen section

Assessment of delineation of pathological tissue from the normal tissue examined with the operating microscope alone is not always accurate. In authors' experience, even after *apparent* clean margin following total or extensive cordectomy, the incidence of positive margin was as high as 25%, showing dysplasia or micro-invasion. The authors therefore routinely advocate frozen-section examination at the conclusion of excision. The following protocol is followed for laser-assisted excised specimens for frozen section examination:

- Careful haemostasis of the lased surgical site is carried out by placing ephedrine soaked pledgets on the operating site. Next, a thorough cleansing of the bed is undertaken with pledgets soaked in normal saline. Any layer of charred tissue, debris and traces of blood are meticulously removed.
- Laser is set at 0.1 second single shot exposure, with a power of two to three W in superpulse mode delivered in a beam diameter of 250 μm. These settings ensure char-free surfaces of excised tissue. Serial biopsies are then taken from the operated site.
- Further tissue removal is undertaken until serial biopsies from the operation site are reported to be *histologically* clear of any neoplastic tissue. Intra-operative frozen section monitoring ensures a high degree of accuracy for removal of the malignant lesion. Of course, it does add to the operating time but this is inconsequential, since, any revision surgery for residual cancer is always that bit more difficult on account of scarring which hinders assessment of anatomical landmarks (Remacle *et al.*, 2010).

8. Postoperative management

A competent postoperative care is vital, especially for supraglottic or hypopharyngeal surgery where an aspiration hazard exists, although such a risk is distinctly minimal, compared to open surgery (Bernal-Sprekelsen *et al.*, 2004; Sasaki *et al.*, 2006; Schroder *et al.*, 2008; Sesterhenn *et al.*, 2006).

9. Glottic cancer: review of the literature

Endoscopic laser surgical excision is now a well-established treatment modality for T1-T2 glottic cancers. Encouraging reports from several workers have focused the debate on the *extent* of endoscopic excision. Reports of laser usage for T3 and T4 lesions are sparse (Bernal-Sprekelsen *et al.*, 2009; Christiansen *et al.*, 2006). Motta (1997) reported laser application in selected T3 lesions. Steiner (2001) is a strong protagonist for including T4 cancers in endoscopic laser excisions.

The following paragraphs cover a review of the literature dealing with the endoscopic laser management of glottic tumours ranging from TiS to T4 over the past ten years. There have also been some useful reviews published in the literature in the past ten years (Bradley, 2009; Agrawal, 2008; Peretti, 2006; Ambrosch, 2007). The authors strongly recommend that any prospective or established surgeon refer to these articles, particularly while dealing with the advanced cancers such as T3 and T4.

Table 1. Literature review of laser management of early glottic cancers (Tis, T1 a/b, T2)

Author	*Study period*	*Study cohort*	*T*	*Survival*	*Rate (%)*	*Larynx preserved %*	*Remarks*
Rucci *et al*., 2010	Up to 55 months	81	Tis 15 T1a 53 T1b 13	Disease free	74%	100	Study on anterior commissure involvement
Ansarin *et al*., 2009	8 years 5 years	274	T0 2 Tis 22 T1a 220 T1b 10	Disease-free Overall	88.2 90.9	97.1	2nd laser procedure: 36 cases RTX: 36 cases
Ferri & Armato, 2008	24-86 months Average follow up: 36 months	45	Tis 9 T1a31 T1b 5	Actuarial 2-year recurrence-free Actuarial 5-year recurrence-free	92.3 89.2	97.6	Diode laser
Hartl *et al*., 2007	At least 2 years Mean follow-up : 56 months	79	Tis 21 T1a 51 T1b 7	Actuarial 5-year overall recurrence –free Actuarial 5-year disease-specific	89 97.3	96% if free margins	
Peretti *et al*., 2004	12 years	322	Tis 37 T1a 191 T1b 55 T2 39	5-year overall	88%	97%	Ultimate control with laser alone 91%
Gallo *et al*., 2002	14 years	151	Tis 12	3- year overall	83.2		Local control 100%
			T1 a 117		96.5		Local control 94%
			T1b 22		95.4		Local control 91%
Eckel *et al*., 2000	9 years	285	Tis 31	Actuarial 5-year cause-specific	100	100	Initial local control: 85.9%
			T1 161		98.5	93.9	Local control after salvage: 98.5%
			T2 93		98.2	93.1	

It is now well documented in the international literature that TiS and T1a glottic tumours carry the best prognosis. However, most recent large studies on transoral laser treatment of *early* glottic cancer comment on the treatment results by incorporating Tis, T1a/b and T2 in the same series. The authors believe that T1b lesions with anterior commissure involvement, and T2 lesions, require more comprehensive preoperative evaluation to ensure the status of the preepiglottic and paraglottic spaces, and penetration of the laryngeal cartilaginous framework, which is often underestimated.

Table 1 includes some of the aforementioned studies for early glottic cancer, followed by comments on the individual studies, where applicable.

9.1. Tis and T1a glottic tumours

Eckel *et al.* (Eckel HE, 2000) reported results in three categories:

- A cause-specific survival of 100%
- An ultimate local control (on repeat surgery) of 100%
- a larynx preservation rate of 100% in 31 patients with glottic cancer.

However, in a larger cohort of 161 patients, these rates fall to 98.5%, 98.2% and 93.9% respectively. T1 tumours were not subdivided to T1a or T1b.

According to Gallo *et al.* (2002), local control of Tis and T1a reached 100% and 94% respectively, although the three-year survival rates were different and were affected by causes irrelevant to the patients' disease. Similar results were also published by smaller studies performed by Hartl (2007) and by Ferri and Armato (2008), the latter being with diode laser.

A large series of 322 patients with Tis-T2 lesions, studied by Peretti *et al.* (2004), revealed a 97% laryngeal preservation rate with a 88% disease-free survival rate and a determinate survival rate of 99%.

In a nine-year follow up of 285 cases, most of them being T1 and T2 lesions, Eckel *et al.* (2000) reported an overall rate of 94.3% for laryngeal preservation, with a five-year cause-specific actuarial survival rate of 98.7% and a local control of 98.5%.

Ansarin *et al.* (2009) reported an overall survival of 90.1% at five years, a disease-free survival of 88.2% at eight years and an organ preservation rate of 97.1%.

Rucci *et al*. (2010) focused on Tis and T1 lesions, as well as involvement of the anterior commissure (see below), commenting on the achievement of a 100% larynx preservation rate and a 74.07% initial control rate, with better controls largely depending on the type of cordectomy undertaken.

9.2. T1b glottic tumours

There is a controversy amongst authors as to the role of laser excision in cases where the tumour extends to *both* vocal folds and the anterior commissure. In their opinion, laser excision of such cases seems to result in higher recurrence rate. Piquet and Chevalier (1993), Wolfensberger and Dort (1990), Krespi and Meltzer (1989), Chiesa *et al.* (1991), and Frèche (1988) go so far as to believe that invasion of the anterior commissure contraindicates CO_2 laser-assisted endoscopic excision. However, Peretti (2004) states that the superficial extension of the tumour to the anterior commissure rarely involves thyroid cartilage since Broyle's ligament provides an effective barrier to its spread. European Laryngological Society addressed this controversial issue in 2007, by allocating a stand-alone type cordectomy: type VI cordectomy (Remacle, 2007) when anterior commissure is involved.

In authors' opinion, involvement of the anterior commissure is always significant because it is the area of least resistance of the thyroid cartilage: there is no perichondrium and ossification occurs early. The safety margin between the cartilage and the tumour is often less than three mm, which is insufficient for adequate clearance. Additionally, endoscopic exposure of the anterior commissure is more difficult and requires significant surgical expertise. Indeed, once the cancer reaches the thyroid cartilage, it qualifies as a stage T4 cancer.

By proposing a classification system previously based on the involvement of the anterior commissure, Rucci *et al*. (1996; 2010) implied that T1 tumour recurrence was more frequent when the tumour, located in one subsite, crossed the midline and in doing so, involved the anterior commissure. However, the finding could not be considered statistically significant since the number of cases was small.

Table 2. (From Rödel, 2009)

The Kaplan-Meier-estimated 5-year control rate	*With anterior commissure involvement*	*Without anterior commissure involvement*
T1a	73%	89%
T1b	68%	86%
T2a	76%	76%

Larynx preservation rate	*With anterior commissure involvement*	*Without anterior commissure involvement*
T1a	95%	98%
T1b	88%	100%
T2a	89%	95%

The larynx preservation rate for the entire group was 95%.

The importance of anterior commissure involvement in influencing prognosis is stressed in many studies as shown in various tables.

In a retrospective study of 444 patients with T1a, T1b and T2a lesions (see T2 classification in paragraph 9.3). Rödel *et al*. (2009) demonstrated that, of the 17% who developed recurrence, half of them had primary anterior commissure involvement. Table 2 clearly shows a better Kaplan-Meier-estimated five-year control rate and larynx preservation rate in cases where anterior commissure was not involved.

In a cohort of 44 cases of T1a-T2 glottic cancer (Table 3), Chone *et al*. (2007) reported a lower recurrence rate in a mean follow-up period of 44 months.

Table 4 shows findings of Steiner *et al*. (2004) for larynx preservation.

Table 3. (From Chone, 2007)

Recurrence rate	*With anterior commissure involvement*	*Without anterior commissure involvement*
T1a – T2	73%	89%
T1b	68%	86%
T2a	76%	76%

Table 4. (From Steiner *et al*., 2004)

Larynx preservation rate	*With anterior commissure involvement*	*Without anterior commissure involvement*
pT1a	93%	99%
pT1b	88%	100%
pT2a	93%	97%

9.3. T2 glottic cancer

Although an increasing number of workers subscribe to the view that the endoscopic laser excision of T1 glottic tumour is a viable option, the same cannot be said for T2 lesions. The controversy arises due to departure from the standard TNM classification. Some authors consider the cord mobility an important issue and subdivide the T2 lesions into T2a (cord mobility *unimpaired*) and T2b (cord mobility *restricted*). Thus, when considering the results from the published series, it is necessary to take into account the variation in the classification introduced by the individual author.

Steiner (1993) places the *T2a* tumours within his group A, with an adjusted survival rate of 100%, and puts the *T2b* tumours (38 cases), along with the T3 and T4 tumours in his group B. For this group B, he reports overall 5-year survival rate of 59% and local recurrence rate of 22%.

Based on a series of 104 *T2a* tumours, Motta *et al.* (1997) achieves an overall survival rate of 67% and an adjusted survival rate of 77%. Based on a series of 54 *T2b* cancers, he observes an overall five-year survival rate of 82% and an adjusted survival rate of 90%.

Based on a series of 36 T2 glottic and *subglottic* cancers, Eckel and Thumfart (1992) achieved complete excision for all cases.

In a small series of eight cases, Rudert (1995a) reports a local recurrence rate of 12.5% (1 case).

Eckel (2001) observed 15.4% (14/91) local recurrences for T2 lesions. The disease-free survival rate excluding recurrence is 74.6%.

9.4. T3-T4 glottic cancer

Most authors reject T3 and T4 tumours as *primary* indications for laser-assisted endoscopic surgery. Endoscopic surgery is then considered for well-defined cases in which a major external excision is not an option. Such cases include poor risk patients. The management strategy for such patients includes as wide an endoscopic excision as possible. This is followed by postoperative radiotherapy to the primary site and to the lymph node groups. The authors favour this therapeutic strategy.

However, according to Steiner (1993), laser-assisted endoscopic surgery *is* indicated for T3 (17 patients) and T4 (six patients) cancers, and he places them in his group B category together with T2b glottis and supraglottic lesions. Motta *et al.* (1997) accept selected T3 cancers for laser-assisted endoscopic surgery: based on a series of 37 cases, they report an overall five-year survival rate of 55% and an adjusted survival rate of 67%. A more recent multicentre study (Hinni, 2007) involving 117 patients with stage III and stage IV glottic and supraglottic cancers (pT2-pT4) treated with transoral laser surgery ± neck dissection ± radiotherapy over a period of seven years showed that the actual two-year laryngeal preservation rate was 92% (83 of 90) and the Kaplan-Meier estimate of laryngeal preservation at five years was 86%. For survival outcomes, the two-year and five-year estimates of overall survival were 75% and 55%, respectively, whereas the two-year and five-year estimates of disease-free survival were 68% and 58%, respectively. Overall and disease-free survival did not differ substantially between patients treated with transoral laser surgery alone and patients treated with laser and adjuvant radiotherapy.

10. The natural history of glottic cancer

Anatomy of the glottis and the natural history of glottic cancer lend well to endoscopic management. The diagnosis can be made relatively early, and therefore, the tumour is small. Moreover, it has a low propensity to nodal spread.

11. Endoscopic anatomy of the vocal folds

The free edge of the vocal fold extends from the anterior to the posterior commissure. In most cases, it is easily accessible with direct laryngoscopy. However, its lateral fan-shaped extension is covered by the ventricular band, which must be removed, at least in part, in order to expose the superior surface of the true cord. The limit of lateral spread is the medial surface of the thyroid lamina in the anterior and middle third and the arytenoid cartilage in the posterior third. The soft tissue thickness between the free edge medially and the cartilages laterally is not uniform, due to angulation of the thyroid ala. Soft tissue thickness is two mm in the anterior third, nine mm in the middle third, and five mm in the posterior third of the vocal fold (Davis *et al.*, 1982; Schlosshauer and Stadtler, 1982). It is clear that there is a natural resistance to tumour spread in the anterior and posterior third of the cord. Consequently, most tumour spread is in the middle third of the cord, where there is maximum soft tissue. The circular or triangular distal end of the laryngoscope should therefore be directed laterally to the diseased side, and secured in position. The soft tissue outside the laryngoscope can be brought into the surgical field by gentle pressure on the thyroid lamina in the neck. This technique is known as 'the third-hand technique' (Chapter 7), since it provides an extra 'hand' for the surgeon. In some cases, the anterior commissure remains outside the laryngoscope. Gentle pressure with the third-hand technique is useful here as well. Once an adequate view is obtained, the laryngeal framework is secured in place by strapping it in the correct position.

12. Laser parameters for excision of glottic cancer

12.1. Laser parameters for subepithelial cordectomy

Subepithelial cordectomy is performed as a phonosurgical procedure which aims to preserve the functional integrity of the vocal ligament while excising the tumour mass. The Acublade™ micromanipulator, which has replaced the Acuspot™, is a scanning software modification that allows the beam to be delivered to the target as a straight or curved incision line. The phonosurgical principles of subepithelial cordectomy have not changed with this new accessory. As with the Acuspot™, the Acublade™ is designed for SuperPulse and continuous modes that can originate from the same optical cavity. Additionally, the Acublade™ is available with UltraPulse technology, which allows for sharper incisions, making the dissection more accurate, mainly when approaching a major vocal fold structure, such as the vocal ligament.

12.1.1. Acuspot setting

With the Acuspot™, the settings can be adjusted to obtain a focused beam of 250 µm in diameter at a working distance of 350 mm. The CO_2 laser is operated in the superpulse mode, to affect maximum cutting. The maximal power setting is 3W.

12.1.2. Acublade setting

With the Acublade™ scanning system, the proposed parameters for SuperPulse are:

- Depth « 0.2mm
- Power setting – 10W
- Exposure time 0.1s
- Single pulse

And for UltraPulse, the settings are:

- Two passes
- Power setting – 10W
- Exposure time 0.1s
- Single pulse

The length of the incision line or the diameter of surface to ablate is one to two mm, depending upon the extent of the lesion. Exposure of 0.1 second duration in single pulses minimises deep thermal penetration, avoids charring, and also allows continuous intraoperative assessment. Injection of saline solution into Reinke's space (hydro-dissection) can make the dissection easier.

12.2. Laser parameters for other cordectomy procedures

Other cordectomy procedures are performed with a slightly defocused beam in order to achieve a zone of coagulum to prevent possible lymphatic spread and also to ensure intraoperative haemostasis. Energy is in the pulse mode, which provides a pulsed beam with continuous power. With these settings, the laser beam 'coagulates' more and 'cuts' less, without producing excessive charring or causing difficulty in tissue identification for histological examination. The exposure is continuous with a minimal power of 8W.

13. Laser technique for endoscopic cordectomy

Depending on the location and size of the tumour, excision can start either anteriorly or posteriorly. Irrespective of the starting point, it is advisable to avoid premature detachment of the entire vocal fold, which would quickly hinder the procedure because of the bulk of the manipulated specimen. The microforceps and suction coagulator help to expose the vocal fold and the plane of dissection.

Wet pledgets, held in a microforceps and pushed into the plane of dissection, are useful for wiping away any charring, and for defining the plane of the tissue. While dissecting the ventricular fold, the vocal fold is protected with a moist cotton pledget or a beamstop. Troublesome bleeding may come from the arytenoid artery or one of its branches. As described by Andrea (1975), such bleeding can also originate from microvessels along the inner surface of the thyroid alae and close to the anterior commissure. The bleeding is easily controlled with diathermy, used with microforceps or on a suction coagulator.

The inner perichondrium must be exposed in order to resect the entire vocal muscle. To facilitate this step, the laryngoscope is tilted and rotated laterally, by about 15-20° from the laryngeal axis. The laryngoscope is positioned in the same way for partial or complete excision. At the thyroid alae, detachment of the vocalis muscle from the thyroid cartilage is relatively easy because of the presence of perichondrium.

At the anterior commissure, the detachment is more laborious because the perichondrium is absent and because Broyle's ligament, formed by the vocal and vestibular ligaments, resists cutting. If the anterior commissure is invaded, it is advisable to maintain plane in the close vicinity of the cartilage. This step is facilitated by following Zeitels' method, starting the excision of the anterior commissure superiorly, with an incision in the petiole of the epiglottis (Zeitels, 1998).

External pressure applied on the glottis by an assistant, or by securing adhesive tape on the front of the neck to immobilise the larynx, allows better exposure of the plane of dissection. The pressure can be exerted either posteriorly or medially on the glottis.

If the patient has not undergone preoperative radiotherapy, and if the microvascular circulation is not compromised, then neither chondritis nor chondronecrosis should occur. In fact, provided the patient is given antibiotics and steroid-antibiotic aerosols during the postoperative period, both complications are rare whatever the preoperative status.

The lased surgical site is covered with fibrin glue in order to avoid postoperative infection, to reduce the risk of granuloma and to promote healing. The inner perichondrium is spared from excessive thermal damage. The integrity of the laryngeal framework is not jeopardised, as it is maintained by the outer perichondrium. Intraoperative tracheotomy is unnecessary, and the patient is extubated in the operating room. Resumption of food intake is usually trouble-free and the patient is allowed to leave the hospital after 24-72 hours. Oral antibiotics as well as aerosols are continued for a week to ten days. Voice therapy begins as soon as the operation site has healed with scar tissue.

Postoperative healing is usually uneventful. Despite the use of fibrin glue, denudation of cartilage can lead to the formation of granuloma. Most granulomas are usually small and do not impede breathing or swallowing. Their typical round shape and grey-pink colour is reassuring. In such cases, the authors refrain from any active intervention and a close surveillance is undertaken while waiting for spontaneous resolution. Aerosols and antacids promote resolution. Granulomas that interfere with laryngeal function due to their size are removed and subject to histological examination. If there is any doubt as to possible invasion of the resection margins, active intervention is necessary. The granuloma together with the surrounding tissue is excised. The entire specimen is sent for histopathological examination.

14. The scope of endoscopic laser cordectomy

Surgery for malignant lesions involves complete removal of the tumour, confirmed by intraoperative frozen-section assessment. By relating the extent of surgery to the anatomical structures of the larynx, the TNM classification of the lesion is undertaken at the conclusion of the operation.

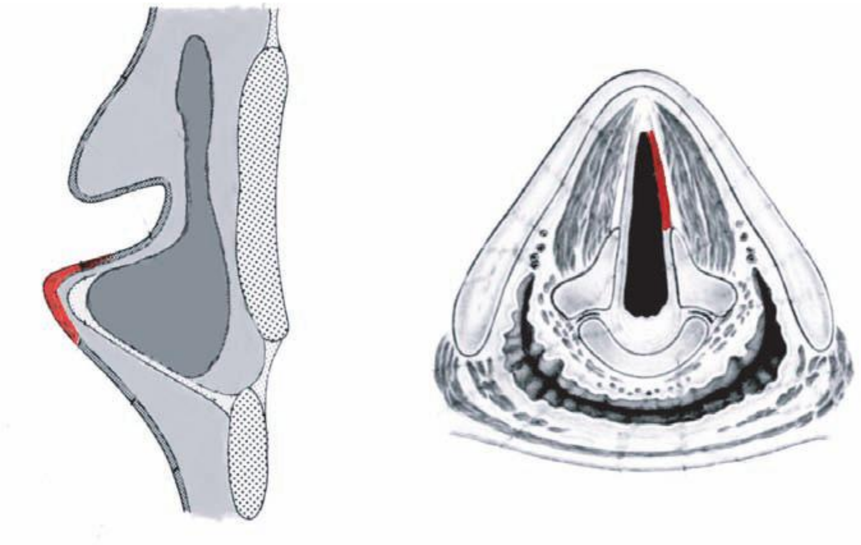
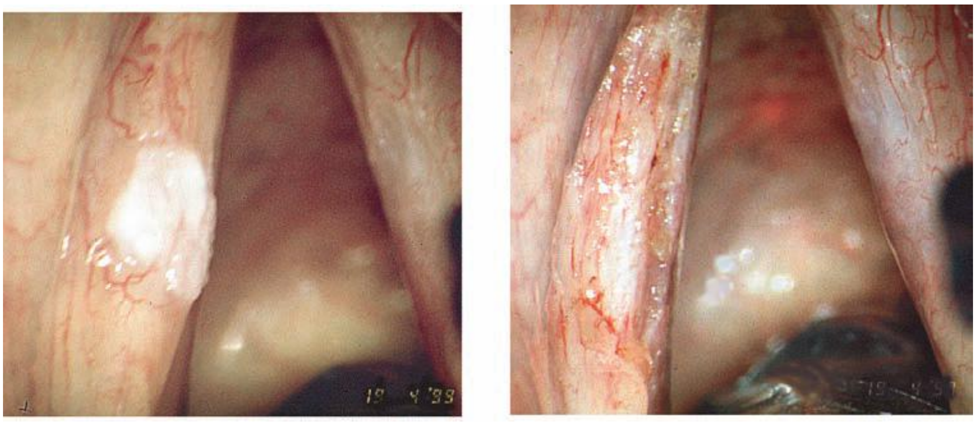


Fig. 2a. Subepithelial cordectomy.



A. B.

Fig. 2b. Subepithelial cordectomy. A. Hypertrophic chronic laryngitis involving the middle part of the left vocal fold. B. Subepithelial cordectomy for histological assessment. Vocal ligament is preserved.

Prior to the introduction of lasers, endoscopic removal of tumours was mostly confined to the removal of the vocal cords: endoscopic cordectomy. This term did not take into account the anatomical or histological extent of surgery, and it encompassed a wide range of surgical removals, from just a few millimetres of the superficial layers to the whole thickness, involving muscles and even the perichondrium. The introduction of lasers added to the confusion, since it allowed even wider endoscopic excision, and the term 'extended cordectomy' was used to differentiate it from 'simple' cordectomy. The lack of standardised terminology meant that the results from one centre could not be matched and compared with the results from another.

The Nomenclature Committee of the European Laryngological Society has taken this issue on board. The personal classifications used by various members were analysed and integrated into a common format. Thus, a new classification (Remacle *et al.*, 2000) was proposed and accepted by the members. This nomenclature takes into account both the histological and the anatomical extent of surgery, and groups it into several categorises.

14.1. Various types of endoscopic cordectomy

The sections below describe the various types of cordectomy. Documentation of cases along the lines approved by the Nomenclature Committee of the European Laryngological Society will allow comparison of results obtained by endoscopic and external surgery, as well as by radiotherapy. Only then will it be possible to rationalise the endoscopic

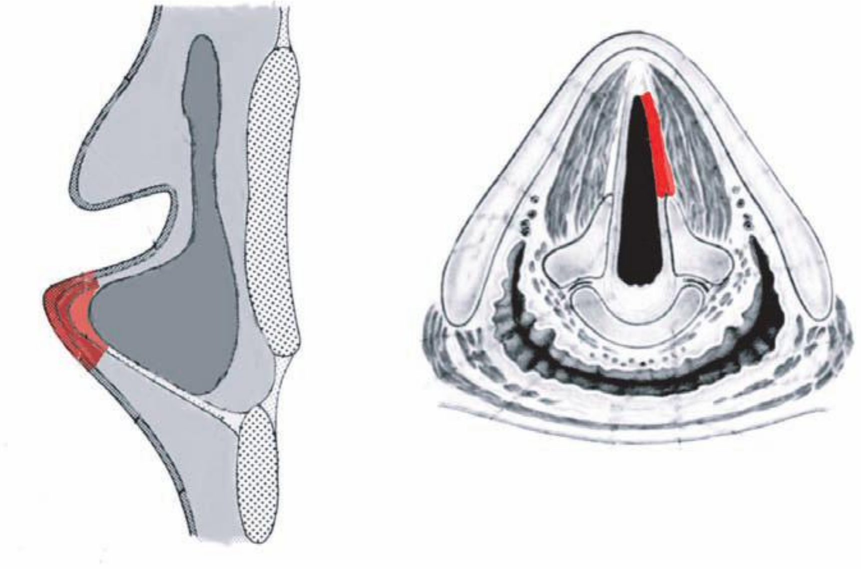
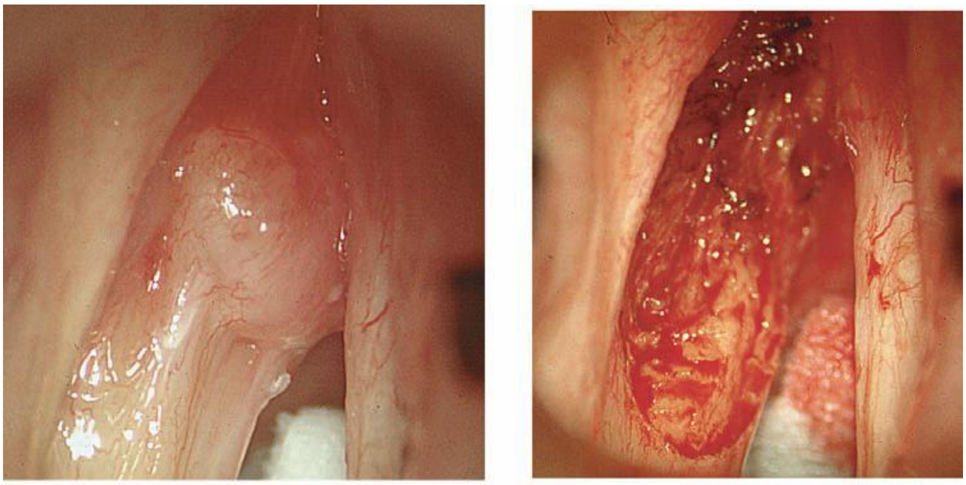


Fig. 3a. Subligamentous cordectomy.



A.

B.

Fig. 3b. Subligamentous cordectomy. A. Superficial, granulating lesion of the anterior part of the left vocal cord. B. Subligamental cordectomy including the vocal ligament and the superficial fibres of the vocalis muscle.

use of lasers for selected lesions, with an equitable outcome.

14.1.1. Type I: Subepithelial cordectomy or decortications

Subepithelial cordectomy (Fig. 2a,b) is mainly diagnostic, since it provides the pathologist with the entire epithelium of the vocal fold. It is performed in cases of chronic hypertrophic laryngitis and consists of the excision of the epithelium and the superficial layer of the lamina propria. The entire epithelium is resected. However, where the epithelial dysplasia is restricted to a relatively small area of the vocal fold, clinically normal epithelium can be preserved. The procedure becomes therapeutic if the histological results confirm hyperplasia, dysplasia, or carcinoma *in situ*, without evidence of micro/invasion. On the other hand, if there are signs of tumour spread, a further and more extensive procedure is required.

14.1.2. Type II: Subligamentous cordectomy

Subligamentous cordectomy (Fig. 3a,b) is performed when the clinical features indicate severe chronic hypertrophic laryngitis, carcinoma *in situ*, or micro-invasive carcinoma limited to the lamina propria. Stroboscopic examination indicates a deeper infiltration: ‘the vibratory silence’. When palpated, the lesion is indurated. Neoplastic transformation is

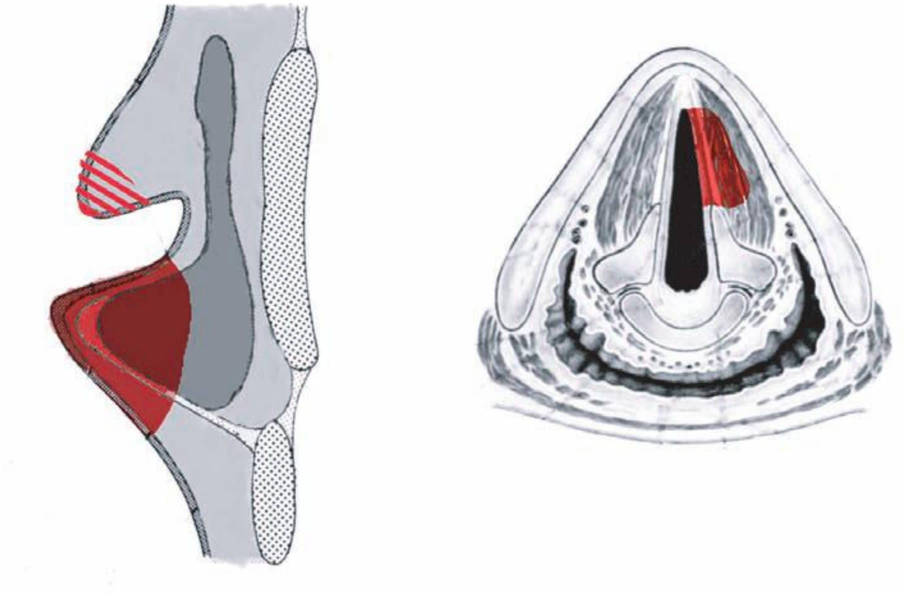
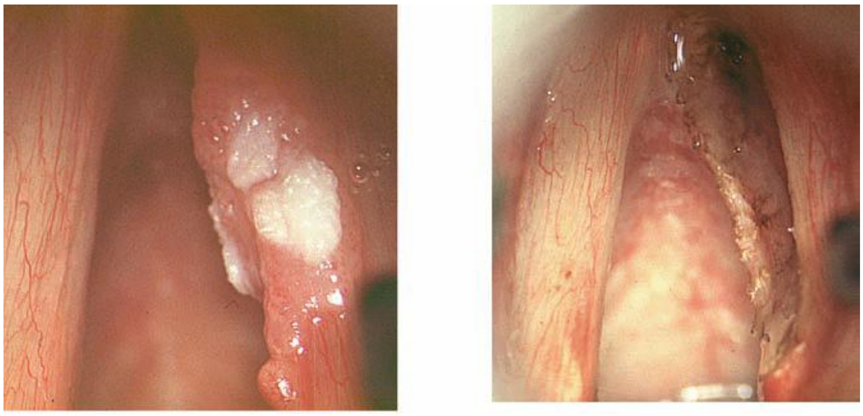


Fig. 4a. Transmuscular cordectomy.



A. B.

Fig. 4b. Transmuscular cordectomy. A. Infiltrating carcinoma of the mid-third of the right vocal fold. B. Transmuscular cordectomy. The conus elasticus is clearly visible under the vocal muscle.

confirmed by histology. Excision of the epithelium, Reinke's space, and vocal ligament is undertaken. The superficial fibres of the vocal muscle may also be resected to obtain adequate clearance.

14.1.3. Type III: Transmuscular cordectomy

Transmuscular cordectomy (Fig. 4a,b) is indicated for small superficial cancers of the vocal fold extending to the muscle. However, infiltration is not deep and mobility is *normal*. Resection consists of the epithelium, lamina propria, and part of the vocal fold muscle, and may extend from the vocal process to the anterior commissure. It is usually necessary to resect the ventricular fold in order to obtain access for adequate excision.

14.1.4. Type IV: Total or complete cordectomy

Total cordectomy (Fig. 5a,b,c) is indicated for T1a cancers diagnosed *prior* to surgery. Therefore, the procedure does not serve any diagnostic purpose and is purely therapeutic. The neoplasm may spread as far as the anterior commissure, but does not involve it. Excision extends from the vocal process to the anterior commissure. Anteriorly, the incision is made at the anterior commissure. It is important to detach the vocal ligament from the thyroid cartilage. Although the lateral surgical margins reach up to the inner perichondrium of the thyroid ala, the excision may be extended to include it in the excised specimen. At times, it may be necessary to remove the ipsilateral ventricular fold partially or

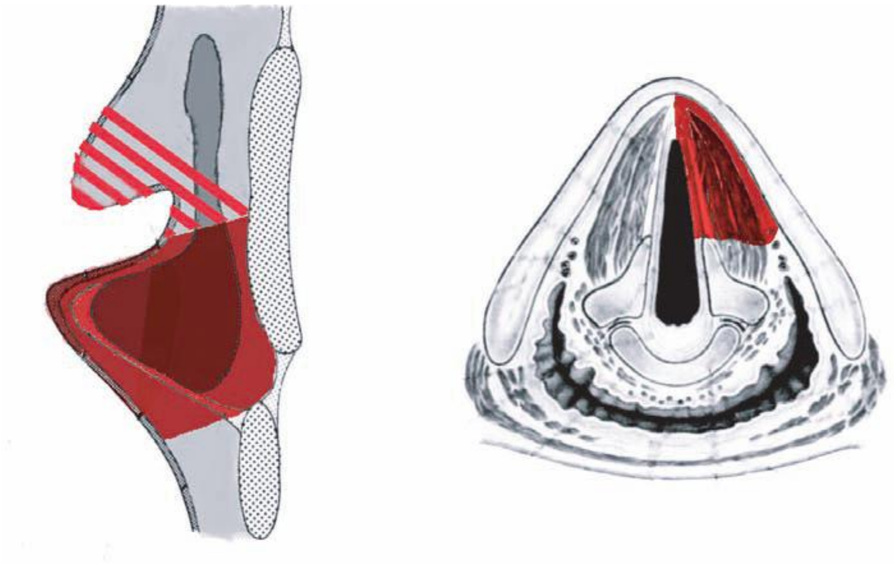
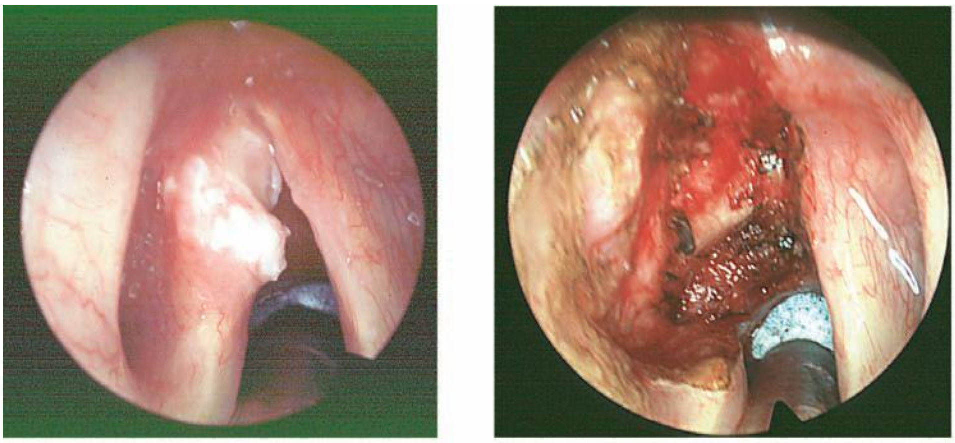


Fig. 5a. Complete cordectomy.



A. B.

Fig. 5b. Complete cordectomy. A. Infiltrative carcinoma limited to the anterior part of the left vocal cord. B. Total cordectomy, including removal of the free edge of the ventricular fold. Thyroid cartilage is left bare, right cord is spared.

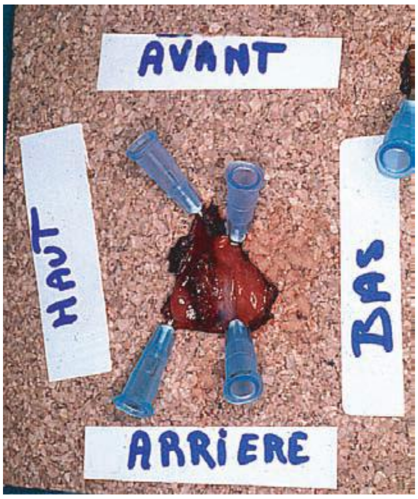


Fig. 5c. Complete cordectomy. Specimen of complete cordectomy fixed and oriented on a cork plate for histological assessment.

completely, in order to ensure adequate resection of the vocal fold.

14.1.5. Types Va, Vb, Vc,Vd: Extended cordectomy

The procedure is the same as that for cordectomy, which is then extended to include the spread of disease beyond the ipsilateral vocal fold. Extended cordectomy is divided into four subtypes. The endoscopic laser management of vocal fold tumours involving the *anterior commissure* presents considerable controversy. Some workers (Motta e*t al*., 1988; Rudert and Werner, 1995a; Steiner, 1993) believe that its excision can be carried out effectively by following the method described later in this section. They maintain that the resection must include the subglottic mucosa and the cricothyroid membrane because cancers of the anterior commissure tend to

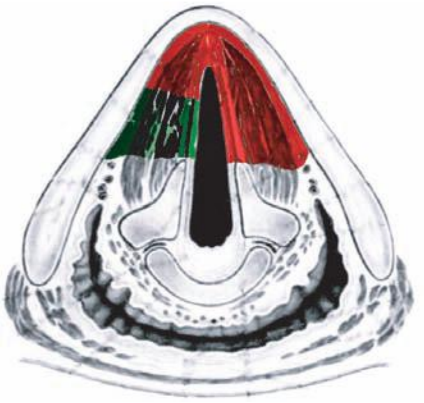


Fig. 6a. Cordectomy extended to the contralateral fold, the anterior commissure is included in the resection.

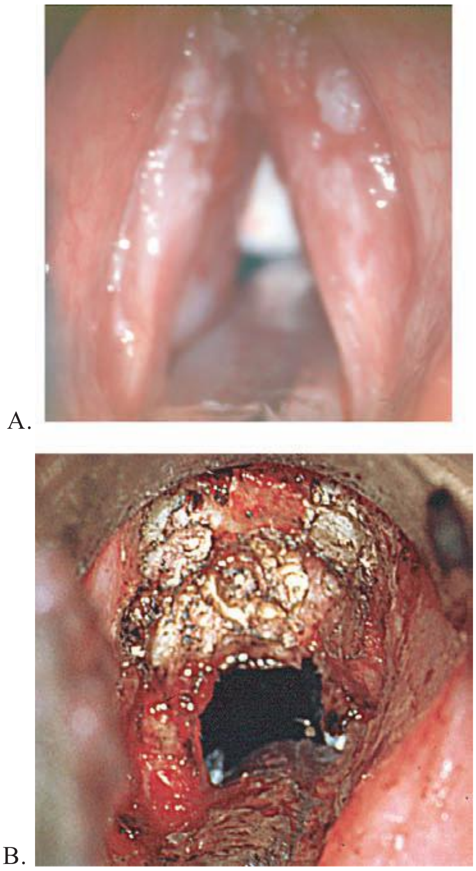


Fig. 6b. Cordectomy extended to the contralateral fold, the anterior commissure is included in the resection. A. Lesion involving anterior 2/3 of both vocal folds. B. Extended cordectomy, the anterior commissure has been resected and the thyroid cartilage is left bare. Superiorly, the petiole was included in the specimen. The posterior part of the vocal folds is spared.

spread via the lymphatic vessels of the subglottic area.

There is an equally vocal body of workers (Krespi and Meltzer, 1989; Piquet and Chevalier, 1993) that believes that carcinoma of the vocal fold, involving the anterior commissure, is a contraindication for endoscopic excision. They consider that resection around the anterior commissure is difficult and, therefore, inadequate.

Some authors (Eckel, 1993; Koufman, 1986; Remacle *et al.*, 1997) favour a compromise, which states that cordectomy extending to the anterior commissure and the contralateral cord is adequate for cancers, provided these structures are involved, but not indurated. Any spread to the base of the epiglottis or subglottis is a contraindication.

14.1.5.1. Type Va: Extended cordectomy

Type Va extended cordectomy includes the anterior commissure and *contralateral* vocal fold, if necessary (Fig. 6a, b). The plane of dissection begins above the insertion of the vocal fold ligament, at the insertion of the base of the epiglottis, and passes through Broyle's ligament. Removal of the soft tissue is carried out on the inner surface of the thyroid cartilage as there is no inner perichondrium at the anterior commissure. If indicated, the excision line is continued to the contralateral side. The ventricular fold on the contralateral side is also removed to ensure full exposure of the tumour.

14.1.5.2. Type Vb: Extended cordectomy – arytenoidectomy

In Type Vb extended cordectomy, the excision is extended to remove part or all of the arytenoids (Fig. 7). The posterior arytenoid mucosa is preserved. Some workers believe that, when the disease extends to include even a part of the arytenoid, endoscopic laser management is precluded. Others believe that endoscopic management of the arytenoid extension is viable, but only if the mobility of the vocal fold is unaffected. Yet others believe that the crucial factor is infiltration of the arytenoids, endoscopic management is contraindicated, if the arytenoid is indurated.

14.1.5.3. Type Vc: Extended cordectomy – ventricular fold

In Type Vc extended cordectomy, the whole of the ventricle and the ventricular fold is removed together with the vocal fold, since the tumour of the vocal fold extends superiorly to involve the ventricular fold or Morgagni's ventricle (Fig. 8).

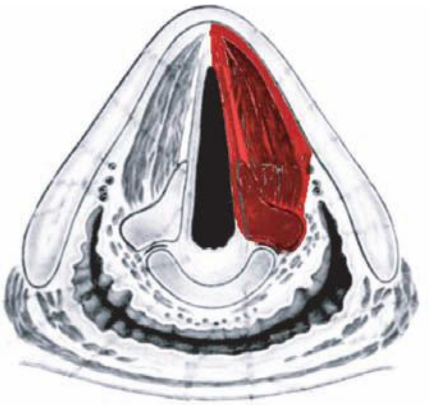


Fig. 7. Cordectomy extending to the arytenoid cartilage.

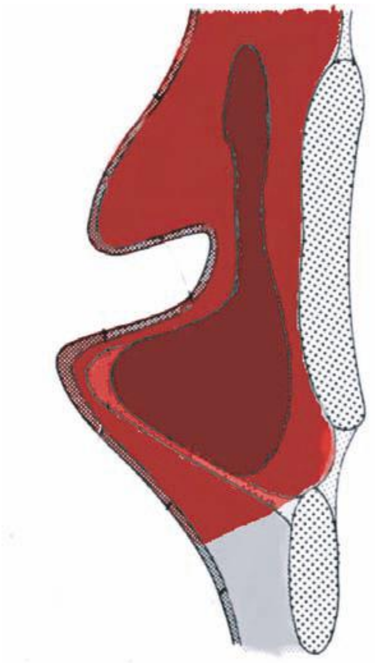


Fig. 8. Cordectomy extended to the supraglottis, including the ventricle and the ventricular fold.

14.1.5.4. Type Vd: Extended cordectomy – subglottis, one cm

In Type Vd extended cordectomy, surgery is extended inferiorly to include the subglottic mucosa (Fig. 9a,b), laying bare the inner surface of the cricoid cartilage. The lower limit of the excision is up to one cm. However, many surgeons consider subglottic spread a contraindication to endoscopic laser surgery.

Adequate endoscopic resection is not always possible because of factors such as incomplete exposure due to an extensive lesion which was not possible to assess accurately. Endoscopic resection is not adequate if frozen sections from the margins prove positive. In these cases, the patient must be warned of the potential limitations of an endoscopic procedure and the possibility of an open procedure at a later stage, should the endoscopic procedure fail to *completely* eradicate the disease. The time taken for endoscopic resection varies from ten minutes for a simple superficial mid-vocal cord cancer to more than one hour for an extended cordectomy.

Per-operative complications are rare, provided laser safety rules are followed meticulously. Tracheotomy is not necessary. Swallowing is resumed under the supervision of a speech therapist, for possible aspiration in extensive resections.

The swallowing usually settles down within a few days. Formation of granuloma, infection, and chondritis are prevented by the application of film of fibrin glue, a course of antibiotics, steroid inhalation and anti-reflux medication. Patients with associated pathology such as diabetes must be closely monitored. Partial glottic stenosis may result due to synechiae, particularly in extensive resections, but is not common, and thus, routine stenting is not necessary.

15. Supraglottic cancer

The endoscopic management of supraglottic tumours is inherently difficult. Since CT scans do not always confirm the deep tumour extension to the *pre-epiglottic space*, endoscopic excision of this space is *mandatory* in all infrahyoid epiglottic cancers, irrespective of CT scan findings.

Unlike glottic tumours, supraglottic cancers can be situated further away from the midline (Fig.10). Technically, the laser beam tends to strike the tumour tangentially and not perpendicularly. Thus, the laser ablation is not as easy as that for glottic tumours. Zeitels (1995) advocates endoscopic excision of supraglottic tumours as an aid for accurate staging. Although he regards the treatment of primary suprahyoid tumours to be curative when the excision margins are negative, he maintains that adjuvant radiotherapy for a T2 or T3 infrahyoid tumour should be advised, regardless of the histological results of the excision margins.

Ventricular tumours are commonly associated with multicentric lesions (Kleinsasser, 1988c). Therefore, the excision of supraglottic tumours should always include the entire ventricular fold in order to prevent a second primary tumour (Fig. 11). The high propensity for lymph node invasion

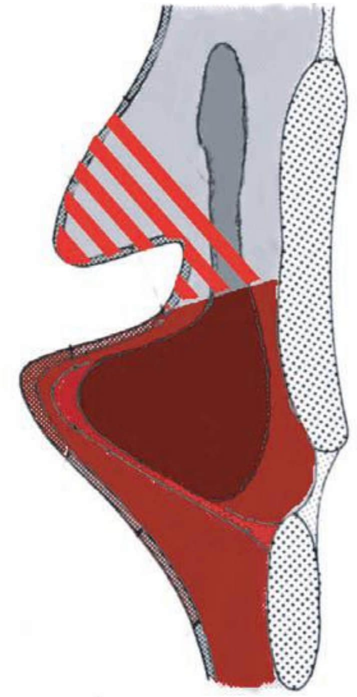
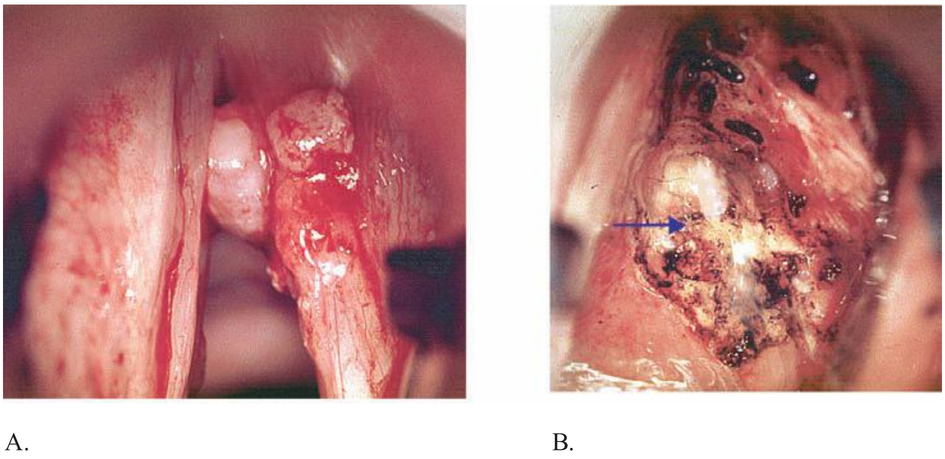


Fig. 9a. Cordectomy extended to the subglottis.



A. B.

Fig. 9b. Cordectomy extended to the subglottis. A. Granulating carcinoma involving anterior 2/3 of the right vocal fold. B. Total cordectomy extending inferiorly to the cricoid cartilage. The thyroid ala and the cricoid are left bare (arrow).

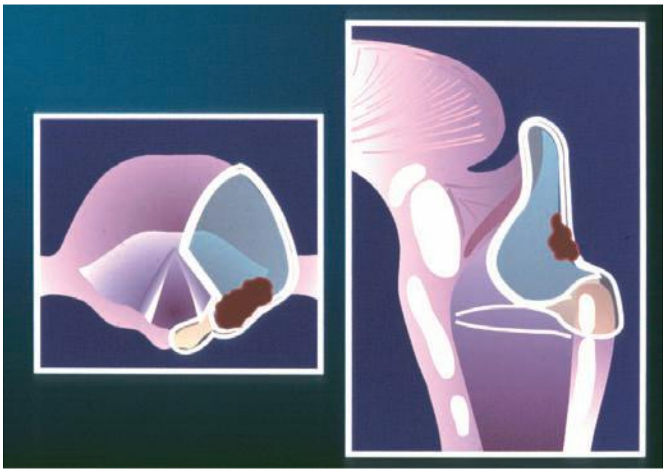


Fig. 10. Endoscopic lateral supraglottic laryngectomy. The procedure can be extended to include resection of one arytenoid.

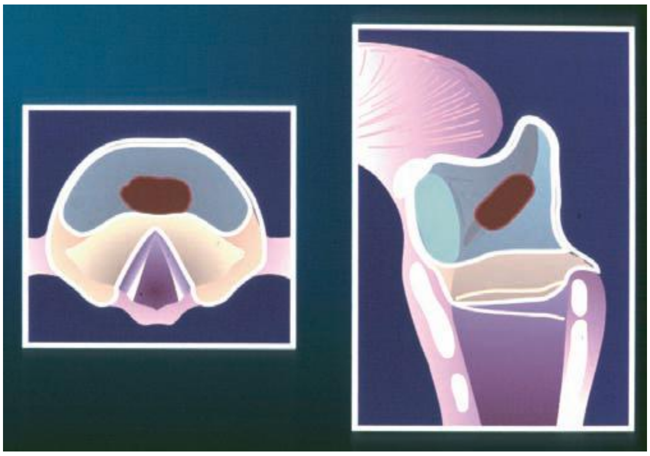


Fig. 11. Endoscopic anterior supraglottic laryngectomy extending to the pre-epiglottic space. One or two ventricular folds can be included in the specimen.

of these tumours requires additional surgical and/or radiotherapy management of cervical nodes. For cancer of the epiglottis, Zeitels (1994; 1995; 1997) stresses the importance of differentiating between supra and infrahyoid lesions. Carcinoma of the suprahyoid portion of the epiglottis does not spread to the pre-epiglottic space (Fig. 12). However, cancer of the infrahyoid portion of the epiglottis often invades the pre-epiglottic space. Indeed, Zeitels noted no invasion of the pre-epiglottic space in a series of nine cases of cancer of the suprahyoid region of the epiglottis. In comparison, he noted occult infiltration of the pre-epiglottic space in as many as 24 out of 27 cases of cancer of the infrahyoid portion of the epiglottis (Fig. 13). These 24 cases had been clinically staged as T2 tumours, when in fact their correct staging was T3.

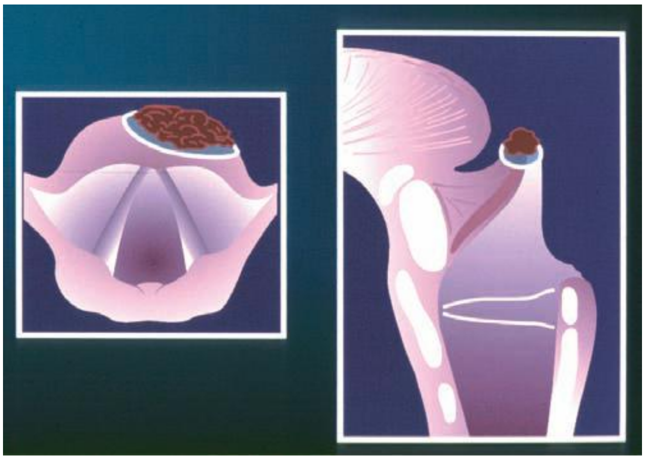


Fig. 12. Endoscopic supraglottic laryngectomy limited to the free edge of the epiglottis.

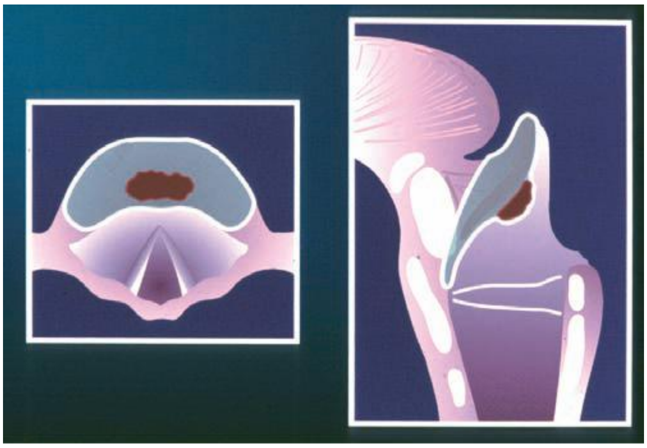


Fig. 13. Endoscopic anterior supraglottic laryngectomy passing through the pre-epiglottic space.

15.1. *Supraglottic cancer (T1-T4 tumours): Review of the literature*

Review of the recent literature shows a number of reports on five-year disease-specific survival following transoral laser microsurgery for supraglottic cancers. Furthermore, functional results are also generally considered superior to those of conventional open surgical techniques. There are further favourable parameters, the overall morbidity and mortality is low, it is possible to avoid tracheostomy, the inpatient stay is shorter and thus, the costs are lower. Larynx preservation rate is also higher than in open surgery group.

In 49 cases with T1 and T2 supraglottic cancer treated with transoral laser microsurgery modality, Karatzanis *et al*. (2010) reported a larynx preservation rate of 94% and a low complication rate of 10.2%, with a mean follow-up period of 67 months.

Another study by Bussu *et al.* (2009) confirmed the effectiveness of laser supraglottic resection by comparing it with the external approach for horizontal laryngectomy for T1-T3 supraglottic cancers. Seventy-eight patients were treated with the external approach, whereas 70 patients were managed with transoral laser surgery. The study showed a five-year disease-specific survival rate of 89% for transoral group as against 80% for the external group. This study emphasises the importance of careful selection of the candidates for laser treatment to ensure that the surgical margin is histologically clear. It also points out the difficulties in accurate assessment of the resected margins due to artifacts resulting from carbonisation. Likewise, anatomical landmarks could not be identified accurately in the specimen.

A similar comparative study for T1-T3 supraglottic cancers was reported by Cabanillas *et al*. (2008). A five-year disease-specific survival rate for the laser group was 80 % as against 72% in the open surgery group. Larynx preservation rate was also better, 86% in laser group against 80% in open surgery group.

Peretti *et al*. (2006) showed favourable functional outcomes for VHI (Voice Handicap Index), GRBAS scores (Grade, Roughness, Breathiness, Asthenia, Strain), voice analysis parameters, VEES (video nasal endoscopic examination of swallowing), and videofluoroscopy in the group of patients with T1-T3 supraglottic cancer treated with laser versus those treated with open surgery.

Grant *et al*. (2007) carried out retrospective study of 38 patients with T1-T4 supraglottic cancer. They reported high two- and five-year Kaplan-Meier estimated local and loco-regional control rate for advanced disease treated with transoral laser surgery with or without adjuvant radiotherapy:100% and 100% for T3, 80% and 80% for T4, respectively. Two- and five-year Kaplan-Meier estimated recurrence-free and overall survival rates were 73% and 67% for T3, and; 53% and 75% for T4 respectively. However, the small number of cases and the selection of patients can influence the results, *e.g.*, overall survival rate for T4 lesions in comparison with T3 lesions

The authors recommend a clinical review by Rodrigo *et al.* (2008) which covers the surgical technique, oncologic and functional results of transoral laser microsurgery and treatment of the neck, for further reading.

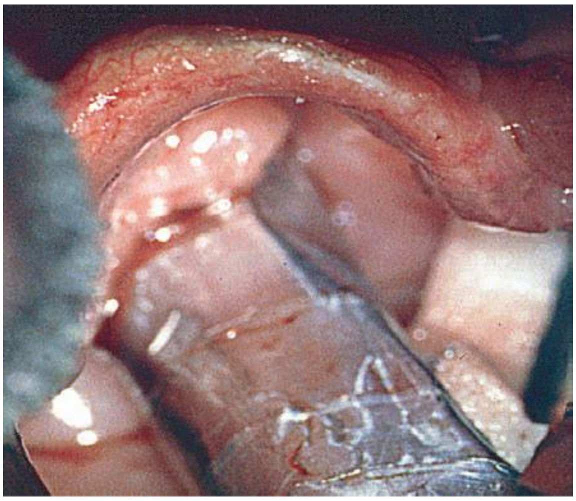


Fig. 14a. Endoscopic laser excision of supraglottic cancer. Carcinoma involving the infrahyoid laryngeal epiglottis.

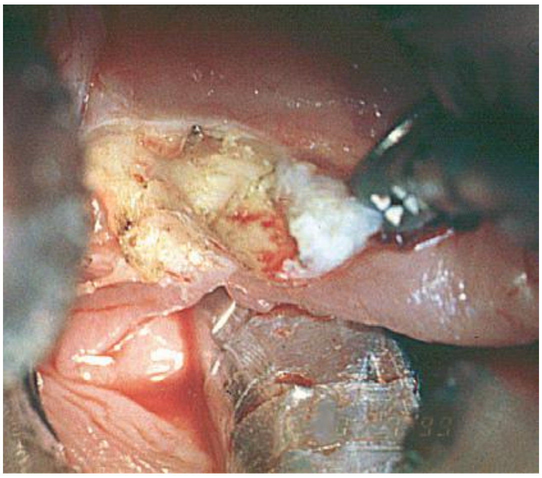


Fig. 14b. Endoscopic laser excision of supraglottic cancer. The dissection of the epiglottis is started from the left side, passing through the pre-epiglottic space.

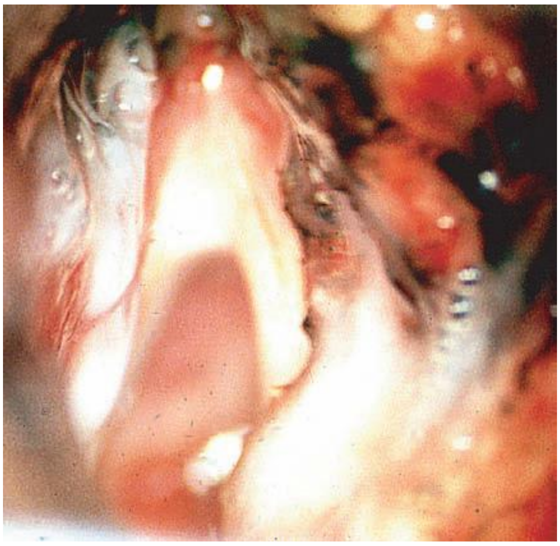


Fig. 14c. Endoscopic laser excision of supraglottic cancer. Supraglottic laryngectomy completed.

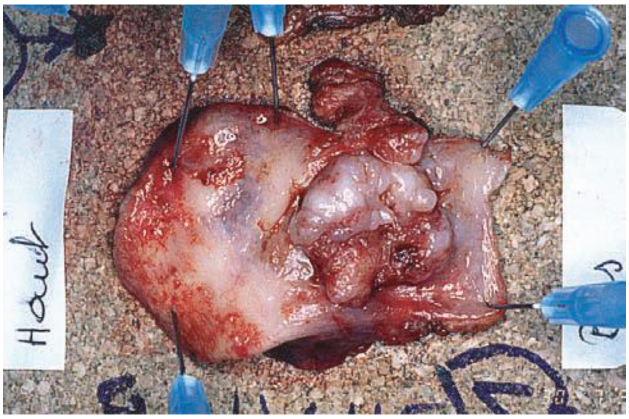


Fig. 14d. Endoscopic laser excision of supraglottic cancer. Specimen of anterior supraglottic cordectomy fixed and oriented on a cork plate for histological assessment.

The introduction of transoral robot-assisted CO_2 laser surgery in the treatment of supraglottic cancer may hold a promise for the future. Chapter 65 covers the present role of robotic surgery for laryngeal cancer.

16. Laser technique for excision of supraglottic cancer

In order to optimise the operating conditions, Zeitels advocates adequate exposure with a Steiner or Weerda bivalve supraglottiscope. One valve is inserted into the vallecula and the other into the pharynx. The energy is set at seven to eight W, with a continuous exposure time and a slightly defocused beam in the pulse mode. The epiglottis is resected at the attachment at the vallecula, thus removing the entire epiglottis or just its upper portion as indicated. In an endoscopic orientation, the superior laryngeal artery extends under the pharyngo-epiglottic fold and may be severed, with marked bleeding. Therefore, if the excision line involves the pharyngo-epiglottic or aryepiglottic fold, diathermy of the area is advisable prior to laser strikes. Some bleeders may even require stapling.

When removing the epiglottis, premature detachment of the hyoepiglottic ligament should be avoided as it results in protrusion of the epiglottis into the surgical field, which impedes surgical progress.

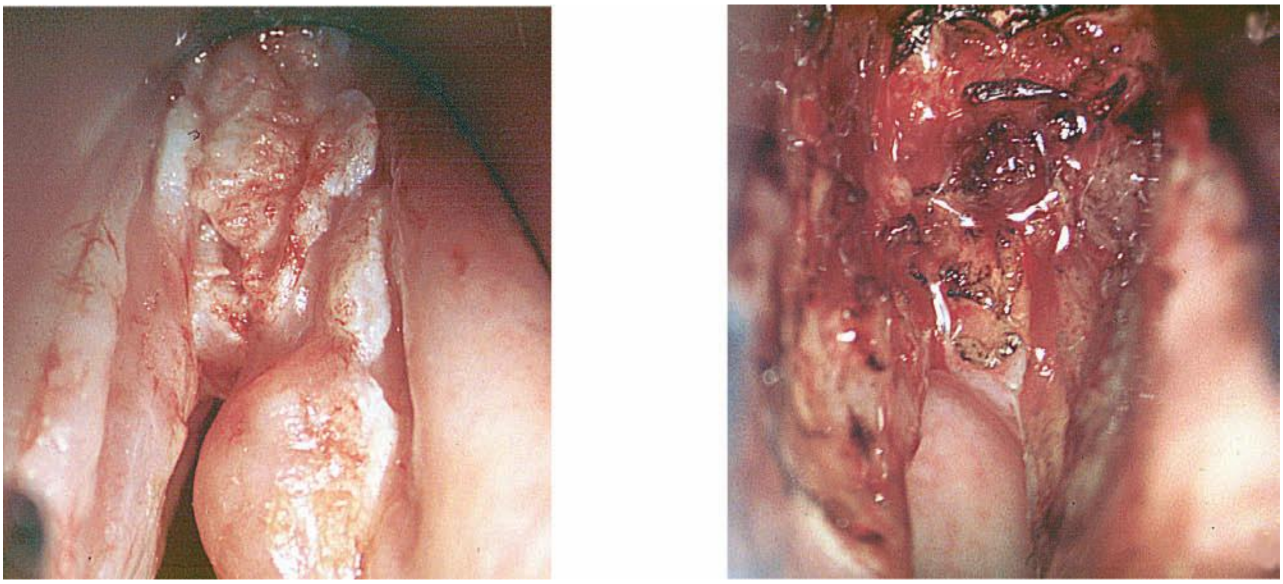


Fig. 15. Verrucous carcinoma of the right vocal fold. A. Verrucous carcinoma of the right vocal fold extending to the anterior part of the contralateral vocal fold. B. Right cordectomy, extending to include the anterior commissure and the part of the left vocal fold.

Orientation of the pre-epiglottic space is critical. Complete endoscopic excision of this area is difficult to achieve, and a great deal of expertise in endoscopic surgery is necessary (Fig. 14a-d). It is vital to systematically identify the surgical landmarks in endoscopic orientation, as follows:

- The hyoid bone;
- The upper edge of the thyroid alae; and
- The intervening thyrohyoid ligament.

As the pre-epiglottic space is opened, it is very easy to 'lose one's way'. In contrast with the glottic area, *en bloc* resection of the whole pre-epiglottic space is very difficult to achieve. Identification of the above landmarks during the procedure facilitates complete resection of the pre-epiglottic space.

Tumours extending into or involving the ventricular bands require removal of the entire ventricular fold, as with the external approach. For these cases, positioning the laryngoscope 15-20° away from the midline is useful.

17. Scope of the supraglottic excision

For the purpose of surgical training, documentation and comparison of results, the European Laryngological Society has proposed a classification of the various laryngeal endoscopic supraglottic partial laryngectomy procedures (Remacle, 2009). This classification comprises four types of endoscopic supraglottic laryngectomy:

17.1. Type I: The limited excision (Fig. 15)

Limited excision is undertaken for small size superficial lesions of the free edge of the epiglottis, the aryepiglottic fold, the arytenoid, or the ventricular fold or any other part of the supraglottis.

17.2. Type II: The median supraglottic laryngectomy excluding the pre-epiglottic space (Figs. 16 and 17)

Median supraglottic laryngectomy is carried out *without* resection of the pre-epiglottic space. It is suitable for T1 lesions of either the suprahyoid or the infrahyoid laryngeal surface of the epiglottis. Type II is further subdivided in to type IIa and type IIb. Type IIa entails superior hemi-epiglottectomy, whereas in Type IIb total epiglottectomy is carried out. The incision line extends to the preepiglottic space but does not aim at removing the pre-epiglottic space entirely. The pharyngo-epiglottic folds, aryepiglottic folds and ventricular folds are preserved.

17.3. *Type III: The median supraglottic laryngectomy including the pre-epiglottic space (Figs. 18 and 19)*

Type III median supraglottic laryngectomy addresses T1 and T2 lesions of the endolaryngeal epiglottis along with the pre-epiglottic space. The entire pre-epiglottic space is removed as far as possible. Type III is further subdivided in to Type IIIa and Type IIIb. In Type IIIa the ventricular band is spared whereas in Type IIIb, the excision extends to remove the ventricular band.

17.4. *Type IV: The lateral supraglottic laryngectomy. (Figs. 20 and 21)*

The lateral supraglottic laryngectomy addresses lesions affecting the three folds or T1 and T2 lesions of the aryepiglottic fold. The procedure removes free edge of the epiglottis ipsilateral to the lesion, the area of the three folds and the aryepiglottic fold. Type IV is further subdivided in to Type IVa and Type IVb. In Type IVa, the ventricular band is removed, whereas in Type IVb, the arytenoid is also removed.

18. Subglottic cancer

Few reports exist on the endoscopic excision of subglottic cancers. Eckel and Thumfart (1992) reported endoscopic excision of seven T2 subglottic cancers in a series of 204 cases of laryngeal cancer. When cancer of the inferior surface of the vocal fold is considered, we subscribe to the view of Piquet and Chevalier (1993) that the laser endoscopic management of subglottic cancer is usually a contraindication. Our philosophy of not tackling subglottic cancer endoscopically is confirmed by the lack of any substantive reports in the literature.

19. Hypopharyngeal cancer

The CO_2 laser-assisted endoscopic management of hypopharyngeal cancers remains extremely controversial. Steiner is the most enthusiastic proponent of the laser endoscopic management of laryngeal cancer at *all* subsites, including hypopharyngeal cancer. His conceptual management is based on the inherent poor prognosis of the disease. The management strategy is surgery, but with the preservation of laryngeal function as concomitant aim. Further rationalisation is sought by him on the premise that laser treatment can be repeated. Moreover, it does not preclude further conventional surgery, radiotherapy or chemotherapy.

Steiner and co-workers (1996) report on the largest series of cases: 103 cases, encompassing 18 pT1 cancers, 63 pT2 cancers, 14 pT3 cancers, and eight pT4 cancers. Ninety-four tumours involved pyriform sinus. The only cases that were excluded from the study were those with invasion of the oesophagus or of the cervical soft tissues. Of these 103 cases, local control was achieved in 93 cases at 44 months. The overall five-year survival rate (Kaplan-Meier method) is 69.5% for stages I and II and 52.5% for stages III and IV.

The CO_2 laser has been used for the treatment of *early* hypopharyngeal cancer by a few workers. A retrospective study by Karatzanis *et al.* (2010) of 119 patients with T1 and T2 hypopharyngeal carcinoma primarily managed with laser surgery showed five-year disease-specific survival and local control rates of 72.6% and 85.4%, respectively.

Martin *et al.* from the Steiner group (2008) have published a large prospective case-series study of 172 patients with early and advanced hypopharyngeal carcinoma. All patients were treated by transoral laser surgery, along with elective neck dissection (93%) and/or postoperative radiotherapy (52%). At a median follow-up of 45 months, five-year Kaplan-Meier local control was 84% for pT1, 70% for pT2, 75% for pT3, and 57% for pT4a. Five-year Kaplan-Meier recurrence-free survival was 73% for stages I and II, 59% for stage III, and 47% for stage IVa.

20. Verrucous carcinoma

Verrucous carcinoma is an atypical form of squamous cell carcinoma which predominantly involves the glottis. It rarely infiltrates and does not metastatise (Ferlito, 1993). Verrucous carcinoma is thus ideally suited for endoscopic resection (Fig. 22).

21. Management of loco-regional spread

Concurrent or sequential lymph node management is dependent upon the size of the primary tumour, and the presence or absence of palpable nodes.

For N0 cases, and depending on the patient's age, radiotherapy to the cervical lymph nodes can be considered.

For clinical N lesions, neck dissection is undertaken following resection of the primary tumour, while awaiting frozen section confirmation of clearance.

Neck dissection is performed conventionally and its extent follows the N staging system. The dissection is followed by elective radiotherapy confined to area of dissected cervical lymph nodes. Radiotherapy plays no role in the treatment of the primary tumour with negative margins.

22. Discussion

The current consensus of opinion is that carcinoma *in situ* (Tis) and T1a cancers are ideal lesions for endoscopic management with lasers. Using a laser for primary excision, Czigner and Savay (1994) reported the control of all Tis cancers and 88% of T1a cancers, without need for adjunct treatment. These survival rates are comparable to other treatment modalities (Davis, 1997; De Vincentiis *et al.*, 1989; Morris *et al.*, 1994; Remacle *et al.*, 1997). However, there are further issues involved in the clinical outcome, which are stated below.

22.1. Outcome measures

Traditionally, in cancer surgery, mortality outcome has always been the leading consideration. However, a recent trend has evolved which considers quality of life as an equally important issue. When considering the appropriate treatment for an individual patient, several factors will influence the outcome. These include the type of the disease, treatment modality, expertise of the surgical team, availability of hi-tech equipment, and last but not the least, socioeconomic factors affecting the community. Within such a wide variation it is still possible to identify a framework and apply some measure of global quality control. In the UK, where the National Health Service is the major health care system, the government has established a department of quality control and standardisation, the National Institute for Clinical Excellence (NICE). Its aim is to assess the performance of individual teams of health professionals with regard to national standards. In view of this trend, several factors described in the following paragraphs are considered for outcome measures.

22.2. Voice quality: Medialisation and/or fat injection

The aim of any surgery for malignancy must be oncological sterility, achieved by removal of the lesion *in toto*. Consideration regarding preservation of voice must not override the method or indeed the extent of surgery. It is important that the voice 'outcome' is considered a result and not the effect of surgery. The result is dependent on several factors which are discussed in the following paragraphs. For further reading, see Chapter 12.

22.2.1. Type of lesion

A T1a tumour may require only a transmuscular cordectomy, or the excision may have to be extended to include arytenoid cartilage. The resultant voice quality will be influenced by the extent of removal, although both conditions will be classified as T1a.

22.2.2. External versus endoscopic surgery

Since endoscopic procedures do not violate the integrity of the laryngeal framework and are usually less aggressive, voice quality is generally better after endoscopic resection, compared to external resection, with reconstruction.

22.2.3. Extent of removal of the vocal folds

Voice quality following cordectomy depends on the *extent* of the cordectomy (Casiano *et al.*, 1991; Hirano and Hirade 1988; Keilmann *et al.*, 1996; Mahieu *et al.*, 1994). The procedure causes little or no modification of the speaking voice because of compensatory phonation with the ventricular folds – the dysphonia plicae ventricularis (McGuirt *et al.*, 1994). In fact, both the formation of a fibrous neocord and the voice therapy will improve voice quality after cordectomy.

22.2.4. Radiotherapy

Vocal fold scarring and dryness can result in the deterioration of voice quality after radiotherapy. An exophytic T1a tumour, treated with radiotherapy, will result in better voice quality than an ulcerative tumour treated similarly.

22.2.5. Healing by synechiae

Healing by synechiae affects the quality of the resulting voice. Synechiae formation has an effect similar to medialisation thyroplasty, as performed by Isshiki. There is more likelihood of synechiae formation if cordectomy has to be extended to the contralateral side in order to include the anterior commissure. In such cases, voice quality is severely affected (Sittel *et al.*, 1998).

22.2.6. Method of assessment

No consensus has yet been reached for comparison of voice quality following endoscopic treatment and after radiotherapy (Hirano *et al.*, 1985). Some authors report no significant difference, irrespective of the method of assessment. These include comparison based on the subjective appreciation of a panel of listeners, and/or objective aerodynamic and acoustic measures (Epstein *et al.*, 1990). Other authors (Rydell *et al.*, 1995) believe that there is a difference in the postoperative outcome of both modalities: voice quality being better preserved after radiotherapy.

22.2.7. Timing of assessment

The assessment of voice quality over a short period will not give true result. For example, radiotherapy may produce better short-term results, which may worsen when full fibrosis sets in, in the months to come. Thus, appraisal of voice quality is a long-term exercise, at any rate, longer than six months.

22.2.8. Vocal fold medialisation

A special problem is vocal fold medialisation after cordectomy. The dense but thin scar tissue in the endolarynx makes medialisation a challenge. Moreover, the increased danger of button holing and implant extrusion with artificial implants makes autogenous cartilage a more favourable alternative (Sittel, 2002). However, good results have been reported by Remacle *et al.* (2001) using the titanium implant in patients after endoscopic cordectomy.

Su *et al.* (2005) report a 92% vocal enhancement following transposition with bipedicled strap muscle in 13 patients that had undergone endoscopic laser cordectomy. The results, in general, are not as good as in patients with paralytic dysphonia, but usually the loss of air during phonation can be diminished and the loudness of the voice increased. Often, additional fat injections are necessary to reach an acceptable result. Bolzoni Villaret *et al.* (2007) reported favourable results with primary intracordal autologous fat injection at the end of transmuscular cordectomy (type III); however, their practice lacks long-term follow up.

22.3. Swallowing

Endoscopic cordectomy does not usually compromise swallowing. However, if cordectomy needs to be extended to include arytenoids, the patient may experience difficulty in swallowing liquids, as in case of patients undergoing arytenoidectomy for the treatment of bilateral vocal fold immobility.

The postoperative course after supraglottic excision carried out endoscopically is usually less eventful than that after open surgery. The sphincter function of the supraglottis is unaffected after a limited excision of the epiglottis. Similarly, unilateral resection of one aryepiglottic or ventricular fold does not affect swallowing. When the excision is more extensive, aspiration may occur for a period ranging from a few days to six weeks, depending on the extent of the excision. During this period, nasogastric tube feeding is recommended.

22.4. Breathing

Endoscopic *laser* surgery for laryngeal malignancy does not require routine tracheostomy.

22.5. Hospitalisation

Hospitalisation following endoscopic laser surgery usually lasts from one to three days. Preserving the integrity of the superior laryngeal nerve which provides sensory supply to the mucosa ensures complete recovery of laryngeal function. The larynx can elevate during swallowing, following uncomplicated healing.

22.6. Previous treatment

Previous radiotherapy or surgery of the larynx results in somewhat prolonged recovery following endoscopic laser cordectomy. Some cases may require 'completion' laryngectomy. The main reason is glottic incompetence resulting from partial or complete bilateral laryngeal immobility, usually due to post-radiation fibrosis and ankylosis. Incompetence leads to intractable aspiration resulting in pulmonary infection.

In post-radiotherapy cases, the margins of resection are ill-defined. Endoscopic resection may therefore be incomplete. Chondronecrosis generally occurs after secondary infection and requires completion laryngectomy.

22.7. *Extra-oesophageal reflux*

Particular care must be taken to prevent pharyngolaryngeal reflux. Antacids can be useful here. Deglutition following endoscopic excision of a hypopharyngeal cancer can be troublesome; the average nasogastric feeding lasts for six days.

22.8. *Cost effectiveness of laser management*

While considering the cost effectiveness, the oncological as well as the functional outcome of various modalities should be equated (Cragle and Brandenburg, 1993). The difficulties in the outcome measures have been discussed earlier.

Despite the differences between the various social security systems, open surgery seems to be the most expensive treatment, and the endoscopic procedure the cheapest. In 1992, Myers *et al.* estimated the cost of CO_2 laser-assisted endoscopic excision to be $12,956, that of radiotherapy to be $32,616, and the one of open surgery, $35,616. Using a notional population of 100 patients as an example, endoscopic treatment would mean a 2.4-million dollar retrenchment.

Based on the 1997 Belgian social security system data, the cost of CO_2 laser-assisted endoscopic excision was €5,450, that of radiotherapy €5,650, endoscopic excision with postoperative radiotherapy €6,250, and open surgery €11,425.

23. Multimodality management

In some patients, the lesion is far too extensive for endoscopic removal. External surgery is then appropriate, but the patient may not be fit to undergo this. Zeitels *et al.* (1994) proposed that endoscopic excision be followed by radiotherapy to the primary site. We support this strategy.

24. Photo Dynamic Therapy (PDT)

Photodynamic therapy consists of the use of photosensitisers to selectively identify and destroy mitotic cells. When administered, the photosenstisers are selectively retained in the mitotic tissue for longer period whereas they are metabolised and excreted from the normal tissue within 72 hours. The tumour is then exposed to the laser light which is absorbed by the photosensitiser which still remains concentrated in the mitotic tissue. The resulting photochemical reaction leads to the production of oxygen radicals, which are cytotoxic, thus killing the mitotic cells selectively without any effect on the surrounding normal tissue (Biel, 2002). This treatment modality for cancer was first reported by Manyak *et al.* in 1988. Several studies have shown photodynamic therapy to be effective in the treatment of T1 and T2 cancers of the larynx (Biel, 1994; 1995; 1998; 2006; Feyh, 1990; 1993; Freche, 1990). In particular, these series demonstrated the efficacy of Photofrin-mediated photodynamic therapy as a curative treatment in 85-91% of T1 cases and in 62% of T2 cases of squamous cell carcinomas of the larynx.

Photodynamic therapy has further advantages: there is no scarring, the voice preservation is excellent and the modality is repeatable. The side effects such as drug intolerance are minimal and the treatment is carried out as outpatient, thus significantly reducing costs**.** For further reading, see Chapter 41.

25. Spectral imaging for the in-vivo detection and mapping of laryngeal malignancy

In current clinical practice, diagnostic methods use white light for *subjective* impression and qualitative assessment of the pathology. Intraoperative clearance is also similarly assessed. White light method has limitations and inherent surgical and histopathology reader-errors. In recent years, several clinical and research centres have been engaged in developing what is loosely termed ‘optical biopsy’. The principle of optical biopsy is based on detecting considerable alterations in structural and metabolic status that occur in malignant, premalignant and infective processes, producing specific changes in *optical* characteristic of tissue. Alterations in tissue composition can be recorded by measuring absorption, fluorescence or scattering signals.

Extensive *in vitro* and *in vivo* studies in various organ systems have successfully demonstrated the potential of fluorescence spectroscopy, based on *spectral* differentiation between normal and abnormal tissue. Spectral imaging technology provides data at high spectral resolution constituting a powerful research tool. It enables non-invasive analysis of tissues *in situ* in their physical environment. For further reading, see Chapter 66.

25.1. *Assessment of margin*

Various studies have demonstrated the need for perioperative assessment of surgical margins in laser endoscopic resection of early glottic cancer (Crespo AN, 2006). Ansarin *et al*. (2009) showed that laser removal of early glottic cancer is oncologically adequate with margins greater than one mm from the tumour edge. Remacle *et al.* (2010) proved the necessity and reliability of fresh frozen section in laser assisted cordectomy cases.

In laryngeal surgery lesions such as T1 or T2 glottic malignancy and dysplasia can be identified and mapped, quickly and safely. The mapped area is then removed with the CO_2 laser beam. At the conclusion of excision, further mapping provides control with negative margin. The precision of excision thus has a potential of better functional result since only the diseased tissue is removed; normal tissue is preserved beyond the negative margin. Although experimental at the time of writing, it has a wide scope in better diagnostic and therapeutic management of laryngeal malignancy. Chapter 66 provides a detail description of the fascinating topic of spectral imaging.

26. Narrow-band imaging (NBI)

The introduction of narrow-band imaging (NBI) in the preoperative, peri-operative, and postoperative endoscopic assessment of laryngeal and hypopharyngeal cancer has improved identification of superficial mucosal lesions that would be missed by conventional white light endoscopy, in view of their neo-angiogenetic pattern of vasculature. Narrow-band imaging relies on the principle of depth of penetration of light, with the narrow-band blue light having a short wavelength (415 nm) penetrating into the mucosa and highlighting the superficial vasculature. Furthermore, the blue filter is designed to correspond to the peak absorption spectrum of haemoglobin to enhance the image of capillary vessels on surface mucosa. A prospective study by Piazza *et al.* (2010) showed that the intraoperative use of NBI coupled with high definition camera (HDTV) improved the rate of diagnostic accuracy from 20.8% (without HDTV) to 42.7%. In addition to that, the use of flexible NBI videoendoscopy during follow up led to an early detection of recurrences and metachronous tumours with an overall gain of 9.2% compared to standard white light endoscopy. The combination of HDTV-NBI showed a sensitivity of 98%, a specificity of 90% and an accuracy of 92% for the entire group of the 279 patients studied. However, limiting factors, such as learning curve and post radiation inflammatory changes, must be taken into account.

27. Other laser indications in cancer management: Palliation

Apart from the curative modality, lasers can be used for symptomatic relief and also as a preliminary procedure to relieve obstruction by large tumours before a more definitive treatment by way of surgery or radiotherapy is instituted.

28. Laser debulking

Debulking is carried out to reduce tumour bulk (Davis *et al.*, 1981; Shapshay *et al.*, 1988), either as a palliative treatment for an incurable recurrent lesion or in order to avoid tracheotomy. The latter situation can occur with an obstructive tumour causing dyspnoea. The laser debuling allows temporary option to bypass the obstructed airway while the appropriate management regime can be planned without the need for urgency. Previously, the Nd:YAG laser was advocated for this because the CO_2 laser is relatively time-consuming. The availability of the Surgitouch™ flashscanner has overcome this drawback; it is now possible to remove large bulk of tissue in a relatively short time. The flashscanner consists of a set of mirrors with rapid rotation of a laser beam of a selected diameter. This allows the quick and safe vaporisation of tissue a few hundred microns thick, layer by layer. The loss of tissue is immediate, with very little deeper thermal damage. Thus, in the postoperative period, there is no risk of inflammatory oedema obstructing the airway again. The energy is delivered in the continuous mode with a power of 25-30W. The flashscanner can also be used to debulk post-radiation oedema in order to avoid dyspnoea and dysphagia, and to access distal sites.

There are only a few studies in the literature regarding the use of laser as a palliative measure in cancer treatment. A study by Paleri *et al.* (2005) advocates the CO_2 laser with the use of a laser-safe anaesthetic tube for debulking supraglottic tumours and a Venturi technique for glottic and subglottic neoplasms. In a total of 43 patients, the CO_2 laser was used in 39 and the KTP laser was used in the remaining four patients in multiple sessions (one to six, with a mean of 1.9 sessions per patient). It was possible to avoid tracheostomy in 91% patients. A review of the literature performed in the same article shows similar success rates (ranging from 90 to 100%) in 6 previously published studies in which the laser was used for tumour debulking. Chapter 17 covers the topic of debulking in detail.

29. Robotics in laser management of laryngeal malignancy

Transoral robotic surgery (TORS) is gaining momentum in the treatment of pharyngolaryngeal tumours in the era of minimally invasive transoral surgery (Hockstein, 2006; Rahbar, 2007; McLeod, 2005). The Da Vinci surgical system (Intuitive Surgical Inc, Sunnyvale, California) is used mostly in oropharyngeal surgery (base of tongue, tonsils), supraglottis and pyriform fossa tumours for the treatment of malignant and sometimes benign tumours (Weinstein, 2007; O'Malley, 2006; Park, 2010; Weinstein, 2007; Moore, 2009). Classically, the DaVinci system uses an electrocautery: monopolar or bipolar diathermy that is manipulated by one of the robotic arms. Its advantages are numerous, compared to traditional endoscopic surgery. Natural hand tremor is filtered out, gross hand movements of the operator are adjusted to small movements of instruments in the airway, thus enhancing dexterity. The surgeon gets a true depth perception by the three-dimensional visualisation of the surgical field (Hillel, 2008).

One drawback of the TORS is the high thermal effect of the electrocautery inducing edema and crusting. Remacle *et al.* have recently introduced a new flexible CO_2 laser wave guide (CO_2 LWG) (Lumenis, Santa Clara, CA) in TORS to minimise the thermal effect and allow for very precise cutting, with effective haemostasis of vessels 0.5 mm or less in diameter. For further reading see Chapter 65.

30. Conclusion

In the medical field, perhaps more than in any other walk of life, an extreme degree of scepticism exists amongst colleagues for the introduction and acceptance of any new hi-tech procedure. There are, understandingly, a number of reasons for this state of affairs.

After many years of arduous apprenticeship, surgeons develop their own strategy of management, based on custom, practice, and their own conviction after a period of professional development. Moreover, technological development is expensive, complex, and requires acquisition of a 'new' skill. Endoscopic laser surgery for the management of laryngeal cancer is no exception.

The authors believe that laser-assisted endoscopic treatment is a feasible option for Tis, T1a, T1b and T2 cancers, provided some very strict and well-defined criteria are laid down and followed, prior to undertaking surgery. These criteria should include surgical access, location and extent of the tumour, and spread to the lymph nodes requiring management by neck dissection or complementary radiotherapy. The protagonists of this approach of extensive endoscopic excision usually perform the neck dissection as a staged procedure.

Within the current management strategy, reconstructive surgery such as crico-hyodo-pexy (CHEP) according to Piquet (1986), or fronto-anterior laryngectomy with epiglottoplasty according to Tucker (1989), is particularly indicated for T2 cancers.

The prospective user should appreciate that this chapter outlines a new type of management for a disease with a potential to fatal outcome. Before embarking upon this new venture, the readers of this chapter would do well to study the various references in detail, and follow the strict selection criteria, surgical practices and follow ups, if they wish to equal or excel the reported results. A visit to the department of any of these experts to watch them in action is perhaps the most rewarding step anyone can take before embarking upon the *routine* laser management of T3 and T4 lesions. An attendance at a laser course will be equally valuable.

The ubiquitous Internet has resulted in better informed patients who may 'demand' a particular option for the management of their disease. It is the professional duty of the surgeon to be aware of all these options. It will be his or her bedside manner that will place confidence in the chosen tailor-made option for the individual. Finally, however skilfully the care is given, there will be a minority of dissatisfied patients who will pick on laser technology as the scapegoat for their recurrence, etc., in the belief that the time-honoured external surgery would have been more suitable. Some lawsuits will be inevitable, but could be well defended, if the management philosophy is well planned and documented before the surgical procedure, with clear-cut objectives and options, and in full consultation with the patient and his or her family.

With this proviso, based on an exhaustive review of the literature and on our own convictions, the authors believe that it is appropriate to consider CO_2 laser-assisted endoscopy within the overall management strategy, where open reconstructive surgery is also a possible option (Remacle and Lawson, 1992). Contrary to the assertion of certain authors (Steiner *et al.*, 1991), a contra-indication to endoscopic management, due to the extent of the lesion, does not automatically call for management with radiotherapy. In such cases, an external procedure remains a viable option. Similarly, total laryngectomy is not the only option after endoscopic failure. In such cases, radiotherapy can still be an option. As a rule, the site and the extent of the tumour determines the overall management modality.

Endoscopic surgery is indicated for Tis and T1a glottic cancers, selected T1b or T2 glottic cancers, and T1 or selected T2 supraglottic cancers.

The conventional management strategy for lesions unsuitable for endoscopic laser management as defined above is beyond the scope of this book. For those who are not used to dealing with the endoscopic excision of malignant tissue from the larynx, we must emphasise that these procedures are not easy to perform. They call for considerable planning. Preoperative assessment of the lesion and the patient, availability of the dedicated instrumentation, an experienced anaesthetist and the nursing team, and a careful follow up, all seriously contribute to achieve results comparable to those published by experts with years of experience.

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MCQ – 11. Lasers in the management of laryngeal malignancy

1. Transoral CO_2 laser excision of laryngeal cancer should be
    a. The first choice of treatment because it is associated with less morbidity
    b. It is a cheaper option
    c. Phonatory outcome is equitable
    d. Laryngeal framework is preserved
    e. Considered only in the context of the overall management of the disease process and not in isolation.

2. Some of the advantages of the transoral CO_2 laser surgery are
    a. Adequate concurrent haemostasis
    b. Minimum postoperative oedema
    c. Low skill demand
    d. There is no cumulative effect since it is ionising radiation
    e. Intensive care nursing is not necessary

3. Any form of laser usage in laryngeal malignancy is not suitable
    a. For elderly patients
    b. If the patient is not compliant for follow up visits
    c. For advanced cancer of the larynx
    d. Unless histopathological clearance is available with frozen section facility
    e. In severe co-morbidity such as COAD

4. CO_2 laser surgery for early glottic tumour is particularly suitable because
    a. These tumours do not have propensity for loco-regional spread
    b. The phonatory outcome is comparable to radiotherapy management
    c. Cure rate is equitable with alternative form of management such as radiotherapy
    d. It is cost effective
    e. Skill demands are not prohibitively high for an average laryngologist.
    f. All of the above

5. Involvement of anterior commissure
    a. Does not pose much problem if it is accessible to laser excision
    b. Represents a disease entity on its own since it can spread to pre-epiglottic space
    c. Is classified separately for excision purposes by European Laser Society (ELS)
    d. According to some authors, Broyles ligament is a natural barrier which prevents the spread of disease in to pre-epiglottis space
    e. According to others, Vocalis muscle fibres are directly inserted in to the Broyles ligament and thus tumour at this location has no natural barrier for its spread into the pre-epiglottic space

6. ELS has classified the various forms of laser excisions for laryngeal cancer
    a. For recovering adequate reimbursement from medical insurance companies
    b. To achieve uniform comparison of outcome between various centres undertaking such work
    c. To replace TNM classification which is obsolete
    d. For surgeons to achieve for optimum phonatory outcome
    e. To protect surgeons against potential law suits

7. T3-T4 glottic tumours
    a. Can be easily tackled with the CO_2 laser by average laryngologist
    b. Can be removed en bloc
    c. Postoperatively, swallowing is never affected since there is no postoperative oedema
    d. Have to be removed layer by layer on account of their bulk
    e. Are tackled trans-orally with the laser only by some protagonists of this method.

8. Management of supraglottic tumours with transoral laser excision is less than ideal since
    a. Infrahyoid tumours may have spread in to the pre-epiglottic space
    b. They are situated more laterally and are therefore struck tangentially by the CO_2 laser beam
    c. They spread locoregionally more often than the glottic tumours
    d. Ventricular tumours are often multicentric
    e. All of the above

9. Surgical outcome in transoral laser surgery for T1 and T2 glottic tumours is usually measured by
    a. Recurrence rate
    b. Phonatory outcome
    c. Cost effectiveness
    d. Morbidity
    e. All of the above

10. Voice quality after Transoral laser surgery is influence by
    a. Life style factors such as smoking and alcohol consumption
    b. Extent of removal of diseased tissue
    c. Type of laser used
    d. Quality of postoperative speech therapy
    e. Measures such as injection laryngoplasty taken to augment the voice
    f. In cases where there is recurrence after transoral laser excision,

11. In cases where there is recurrence after transoral laser excision, further laser excision is not advisable since this modality failed after the first laser excision
    a. Further laser excision is not possible due to its cumulative dosage limitation
    b. Radiotherapy should not be given since it is ionising radiation, similar to the laser radiation
    c. External surgery is more difficult due to excessive scarring produced by the laser usage
    d. There are no prohibitive factor to undertake further management with laser or any other modality

12. Laser used in conjunction with robot
    a. Gives superior result in terms of survival
    b. Will revolutionise the management of subglottic tumours
    c. Is used currently for supraglottic tumours only
    d. Is cost effective
    e. Eliminates hand shake, particularly in older surgical colleagues

13. If the laser is used casually for cancer of larynx there is a danger that
    a. The technology and not the poor surgical skill will be blamed for recurrences
    b. Recurrence is more likely to be due to residual tumour which was left behind inadvertently by a novice to the technology
    c. Phonatory outcome will be suboptimal
    d. There may even be lawsuits for not using conventional methods in case of mortality
    e. All of the above

Chapter 12

Voice outcome after laser management of early glottic carcinoma

F. Núñez-Batalla

This chapter is presented in two parts. Part A assesses the voice outcome following laser management and compares it with that following radiotherapy. Part B describes methods and outcome of various augmentation procedures.

Part A: Comparison of voice outcome after laser management versus radiotherapy for early glottic carcinoma

1. Introduction

The principle objective of the management of any malignant neoplasm is complete eradication of the disease to obtain cure, and cancer of the glottis is no exception. Until recently, transcervical surgery and/or radiotherapy provided a gold standard with a 90% cure rate in most early glottic cancers (Higgings, 2009). These modalities also provided a useful functional outcome, with a very acceptable preservation of voice.

The introduction of transoral CO_2 laser surgery offered yet another treatment option for early glottic cancers. The CO_2 laser management with transoral laser has some advantages. Apart from offering equitable cure rate and functional outcome, the treatment is quicker, there is less morbidity and thus return to work is quicker. The overall cost implications also favour the laser modality.

Although transoral CO_2 laser microlaryngeal excisions provided a viable alternative, a number of institutions continued to manage these cancers with radiotherapy in the belief that it resulted in a better voice quality (Delsupehe, 1999). The choice of one treatment over another should contemplate the cure-rate, larynx preservation rate, post-treatment voice quality, morbidity and treatment cost (Smith, 2003). This chapter covers a critical appraisal of the various parameters which determine the voice quality and then compares it with management by radiotherapy versus transoral laser excisions of early glottis lesions.

2. Review of literature

Various studies have been published comparing voice quality after both management modalities (Piazza, 2003; Tamura, 2003; Wedman, 2002). In some studies voice quality is similar, while in others, authors maintain that the voice is better after radiotherapy than after laser surgery (Krengli, 2004; Pellitteri, 1991; Verdonck-de Leeuw, 1999). Review of recent literature shows two meta-analyses (Cohen, 2006; Higgins, 2009) and twelve retrospective studies (table 1) evaluating voice outcome in T1 glottic cancer treated with transoral laser surgical excision or external beam radiation therapy. However, there are fewer published works that include patients' assessment with regard to the impact that the disease and the treatment have had on their quality of life (Núñez-Batalla, 2008; Loughran, 2003; Peeters, 2004; Stoeckli, 2001).

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2.1. Outcomes comparison of laser excision versus radiotherapy

2.1.1. Perceptual analysis of dysphonia

Voice quality was examined by subjective voice analysis and by the GRBAS score. Both methods showed no significant difference between treatment groups (Núñez-Batalla, 2008), but the results did show a trend towards favouring the RXT group (Higgins, 2009; Delsupehe, 1999; Rydell, 1995; McGuirt, 1994; Epstein, 1990; Elner, 1988; Hirano, 1985).

2.1.2. Videolaryngostroboscopy

Videolaryngostroboscopy showed abnormal patterns in almost all patients. It is not unusual for T1 glottic cancer patients to have abnormal contralateral mucosal waves as a result of a long-term phonotrauma related to their vocal behaviour or vocation, long-term negative effects of smoking and other environmental abuses on the vocal folds (Zeitels, 2002). More than half of the patients in each group had incomplete closure of the vocal folds (Sjögren, 2008). There was no significant difference between treatment groups with respect to the stroboscopic analysis of mucosal wave (Higgins, 2009; Sjögren, 2008; Tamura 2003). Nevertheless, the result showed a trend toward a better outcome for the radiotherapy group (Mlynarek, 2006; Wedman, 2002; Elner, 1988; Hirano, 1985).

2.1.3. Acoustic analysis

Findings have differed from one study to another. The results of the meta-analysis (Higgins, 2009) showed an overall slight trend toward superiority for radiotherapy with respect to fundamental frequency and phonation intensity range, whereas the perturbation measures of jitter and shimmer favoured the laser surgery group (Sjögren, 2008). By contrast, Tamura (2003) reported that all phonetic parameters (maximum phonation time, fundamental frequency, intensity, jitter, shimmer, harmonic-to-noise ratio, etc.) were similar in the laser surgery and the radiotherapy groups. However, Rydell (1995) reported voice quality, both at three months and at two years after radiotherapy, to be significantly better than after laser surgery. There were no significant differences in both groups in narrow-band spectrograms (Núñez-Batalla, 2008).

2.1.4. Aerodynamic Efficiency Analysis

Studies report contradictory findings. According to Higgings (2009), there are significant differences in the maximum phonation time favouring the radiotherapy group in the meta-analysis, while Nunez-Batalla (2008) favours the laser group. However, Sjogren (2008) and Tamura (2003) state that there is no significant difference between a normal group and both treatment groups.

2.1.5. Patient Self Perception Analysis (Voice Handicap Index, VHI)

Six studies in which the VHI was assessed at least three months after treatments for T1 glottic cancer were identified and analyzed by meta-analysis techniques by Cohen *et al*. (2006). The post-treatment VHI scores were similar for the radiotherapy and laser groups. In another study Peeters, (2004) found a significant difference between treatment modalities for the total VHI score with a lower score for the patients treated with endoscopic laser surgery as compared to the irradiated patients. Nevertheless, regarding the statement on overall voice quality, no differences between treatment modalities was found, 70% of the patients reported overall good voice quality. Sjögren (2008) reported that the VHI for most patients is minimal, with few severely affected patients in both groups. There was no significant difference in the total score or in any of the subclass scores on the VHI between irradiated and laser surgery-treated patients.

By contrast, Nuñez-Batalla (2008) reports, upon completing the comparison of VHI scores between the two groups, that the statistical difference is significant in favour of the radiotherapy patients in the functional and emotional ratings as well as on the global scores. No significant differences were found in the physical scales.

2.1.6. Effects of counselling by voice therapist

The effectiveness of voice therapy following partial laryngectomy is controversial. Moore (1975) pointed out the benefits of speech therapy in five areas: strengthening glottic closure and loudness of the voice, improving the efficiency of breath support, increasing the articulatory skill and intelligibility of speech, recognising and compensating for hearing loss and aiding the patient to reduce detrimental environmental influences.

Conversely, Sittel *et al*. (1998) found no evidence of significant benefit from speech therapy after cordectomy, but some authors propose it empirically during and after radiation therapy to prevent the development of supraglottic hyperkinetic dysfunction in cases of type I or type II cordectomies (Remacle, 2006) in order to obtain better compensatory manoeuvres in use of the affected vibratory source and better voice quality (Honocodeevar-Boltezar, 2000).

Zeitels *et al*. (2002) believe that voice therapy, focused primarily on reducing any persistent vocal hyperfunction and on exercises designed to enhance vocal fold entrainment, is crucial to optimizing post-surgical vocal outcomes for selected patients.

Piazza *et al*. (2007) stated that speech therapy only minimally improves vocal outcome and does not help influence vocal fatigue due to wide glottal gaps and stiff scar tissue. The presence of a large glottic gap may facilitate hyperfunctional compensatory behaviour resulting in further dysphonia. Therefore, in specific cases of active and motivated people, a phonosurgical procedure is recommended to close the glottic gap followed by postoperative speech rehabilitation in order to optimise vocal outcomes in the presence of the new laryngeal configuration.

3. Surgery for early glottic cancers

Early vocal fold lesions result in 80-90% cure rate irrespective of treatment with endoscopic laser approach, or open transcervical approach. However, the functional outcome is vastly superior when the treatment is undertaken endoscopically (*e.g*., Keilmann, 1996). In some published studies (Schindler, 2004) this improvement is not as evident. It may be that in laser techniques some patients have undergone more extensive surgery than is oncologically optimal, while in others, phonosurgical augmentation was not undertaken. Recently introduced ultrathin margins and augmentation techniques address this issue. Ultrathin margin ensures optimum removal of disease and, at the same time, preserves maximum normal tissue for a good phonatory outcome. Comparative studies which conclude that the radiotherapy gives an equivalent or superior voice quality, could not have taken into account these more recent developments which employ phonosurgical techniques in the management of early glottic lesions. This modern phonosurgical management follows the techniques of ultra-thin margins during the resection; thus, a 1-2-mm surface margin at the perimeter of the lesion result in an acceptable 3% rate of local recurrence (Zeitels, 2002) and a minimum vocal handicap. The disease is thus eradicated, with maximal preservation of the vocal folds' normal layered structure.

A minimum period of six months of recovery after treatment should be observed before proceeding with assessment. This time period is chosen to allow adequate healing, to verify the absence of early recurrence and to evaluate the voice rehabilitation that can be achieved by voice therapy where indicated (Remacle, 2006).

4. Criteria for case recruitment for assessment of voice outcome

Studies exploring voice outcomes after laser or radiotherapy treatment vary because of problems associated with study design and data collection. There are reports demonstrating favourable Voice Handicap Index (VHI) scores in laser-treated patients (Loughran, 2005; Peretti, 2003). However, these reports include patients with carcinoma *in-situ* lesions. Their voice results may be better since carcinoma *in situ* requires much less invasive surgery, resulting in a bias towards laser management. To overcome such bias, patient cohort should not include carcinoma *in-situ* patients (Cohen, 2006).

5. Methodology for the measurement of outcome

There are several limitations to any conclusions that can be obtained from these studies, mainly owing to the variations in voice-measuring methods (Table 1). Furthermore, voice analysis instruments lack uniformity, reliability and validity. In most studies, only one or two aspects of voice functions are evaluated.

The European Laryngological Society (ELS) recommends that the assessment of pathological voice conditions needs to be multidimensional. A minimal set of basic requirements for presenting and publishing results of voice evaluation is necessary in order to make comparisons and meta-analyses. In the basic set for the assessment of voice outcomes, the following components need to be considered, since all of them provide quantitative data:

a. Perception;
b. Videolaryngostroboscopy;
c. Acoustic and Spectrographic Analysis;
d. Aerodynamic Efficiency Analysis;
e. Patient Self Perception Analysis (Voice Handicap Index) (Dejonkere, 2001).

Table 1. Summary of current literature about voice outcome in T1 glottic carcinoma laser surgery versus radiotherapy

Study	*RXT patients*	*TOL patients*	*Stages included*	*Timing posttreatment assessment (mo:months)*	*Outcome measures*
Nuñez-Batalla, 2008	18	19	T1a,T1b	> 6 mo	Acoustics, aerodynamics, perceptual, self-assessment
Sjögren, 2008	16	18	T1a	> 45 mo	ELS protocol
Mylnarek, 2006	4	5	T1,T2	NR	Stroboscopic
Cohen, 2006	208	93	T1a,T1b	> 3 mo	VHI
Krengli, 2004					
Loughran, 2005	18	18	T1a	28-31 mo	GRABS, Self-assessment
Peeters, 2004	40	52	T1a	> 12 mo	VHI
Tamura, 2003	5	10	T1a	> 12 mo	Acoustics, aerodynamics
Wedman, 2002	9	15	T1a	2-15 y	Acoustics, aerodynamics, perceptual, self-assessment
Rydell, 1995	18	18	T1a	> 3 mo	Acoustics, aerodynamics, perceptual
McGuirt, 1994	13	11	T1a	> 6 mo	Acoustics, aerodynamics, stroboscopic
Cragle, 1993	20	11	T1	> 5 mo	Acoustics, aerodynamics
Elner, 1988	15	10	Tis, T1a	> 12 mo	Stroboscopic, perceptual
Hirano, 1985	14	17	T1a	> 3 mo	Aerodynamic, Stroboscopic, perceptual

6. Perceptual analysis of dysphonia (GRBAS)

Perceptual analysis of the dysphonia should be performed using the GRBAS scale (Hirano, 1981). Each sample can be classified from 0 to 3 (0 = normal, 1 = mild, 2 = moderate, 3 = severe). The severity of hoarseness is quantified under the following parameters:

- G (Grade), which refers to the overall voice quality.
- R (Roughness or harshness): audible impression of irregular glottic pulses, abnormal fluctuations in fundamental frequency and separately perceived acoustic impulses (as in vocal fry); it also includes diplophonia and register breaks.
- B (Breathiness): audible impression of turbulent air leakage through an insufficient glottic closure. May include short aphonic moments (*i.e.*, unvoiced segments).
- A (Aesthenicity): impression of weakness in the spontaneous phonation, hypokinetic or hypofunctional voice.
- S (Strain, vocal tension): auditive impression of excessive force or tension associated with the spontaneous phonation.

7. Videolaryngostroboscopy

Videolaryngostroboscopy is the main clinical tool for the aetiological diagnosis of voice disorders. It can also be used for assessing the quality of vocal fold vibration, and thus the effectiveness of medical or surgical treatment. Basic parameters are glottal closure and mucosal wave, accounting for the physiological integrity of the layered structure of the vocal folds. A quantitative rating is recommended using a four-point grading scale, or a visual analogue scale of 10 cm. For comparisons of pre-/post treatment outcome, it is advisable to use the same type of endoscope (rigid or flexible, if rigid: same angle) at each examination (Dejonckere, 2001).

8. Acoustic and spectrographic analysis

The acoustic analysis should be performed using voice analysis software. The acoustic signal must be recorded at a sampling frequency of 44,100 Hz with a high frequency range microphone. The microphone should be located 10 cm from the patient's

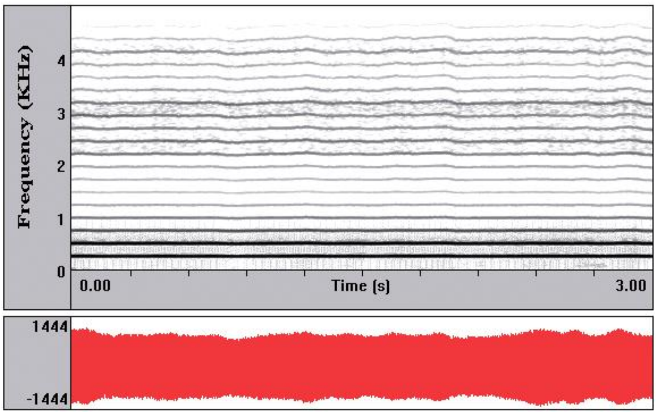

Figure 1-A. Narrow-band sonogram showing a normal voice. Vocal /ae/ at a comfortable pitch and intensity level.

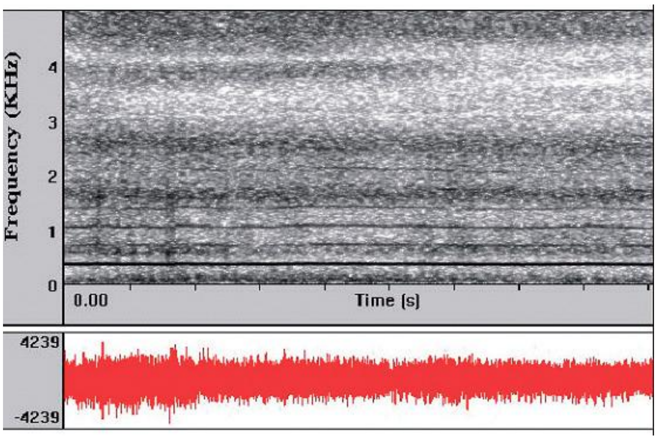

Figure 1-B. Narrow-band sonogram showing a Yanagihara type IV dysphonia. Left type III cordectomy. Vocal /ae/.

mouth while they emit the /a/ sound at comfortable intensity and pitch levels, in a sound-treated room. A quiet room with ambient noise < 50 dB is also acceptable. Once the signal is digitised, the computer calculates the following acoustic parameters:

- Fundamental frequency (F0).
- Jitter or frequency variation (%).
- Shimmer or amplitude variation (%) .
- NNE or Normalised Noise Energy, which measures the degree of noise produced by turbulent air escaping through the glottis during vocal emission.

Using the same digitised voice sample, a narrow-band spectrogram can be generated (Fig. 1-A).

The spectrograms are grouped in four types according to the Yanagihara criteria (Yanagihara, 1967) (Fig 1-B). Also included in the basic acoustic measures are three critical points of the phonetogram (VRP: voice range profile). The highest frequency and the softest intensity (dB A at 30 cm) seem to be the most sensitive parameter for changes in voice quality, the latter being related to phonation threshold pressure. The measurement of the lowest frequency makes it possible to compute the fundamental frequency range (Dejonckere, 2001).

9. Aerodynamic efficiency analysis

This consists of measuring the maximum phonation time (MPT) for the /a/ vocal after instructing the patient to sustain this vocal for the longest time possible in a comfortable pitch and intensity. The patients are asked to repeat the test at least three times, and the highest value is retained. It is one of the most widely used clinical measures in voice assessment. Averaged phonation air flow, or Phonation Quotient (PQ) = Vital Capacity (ml) / MPT (s). Vital capacity (VC) is defined as 'the volume change at the mouth between the position of full inspiration and complete expiration'. It can be measured reliably by using a hand-held spirometer (Dejonckere, 2001).

10. Patient Self Perception Analysis (Voice Handicap Index)

The patient completes the 'Voice Handicap Index' via a self-evaluation form comprising 30 questions covering three domains (Jacobson, 1997): Functional, Physical and Emotional. Each question is assigned a score of 0 to 4 (from least disability to most). In each domain the maximum score is 40 points. A score less than 20 can be classified as mild disability, 21 to 30, as moderate, and more than 30, as severe disability. Adding the three scores together the possible maximum score is 120; the *vocal* disability can then be classified as mild (less than 30), moderate (31 to 60), severe (61 to 90) and very severe (91 to 120). This evaluation of voice, although subjective by definition, is of growing practical importance in daily clinical practice.

11. Vocal outcome after resection

Vocal outcome after endoscopic cordectomy is strictly related to glottic competence, which is modulated by the amount of vocal muscle resected. Zeitels (2002) coded individual patients according to the depth of the initial surgical resection: (1) superficial lamina propria; (2) vocal ligament; and (3) vocalis muscle.

12. Resection of superficial lamina propria

Results of acoustic and aerodynamic assessment showed that lesions confined to the superficial lamina propria, resected superficial to the vocal ligament, had minimal vocal disturbance subsequent to healing and epithelialisation.

13. Resection of the vocal fold

Resection of the vocal fold epithelium and its underlying lamina propria (including vocal ligament), results in the formation of neocord with a concavity depending on the extent of ligament and muscle resection. Voice outcome in this vocal ligament group was comparable to those of the superficial lamina propria cohort. Extending the resection to the paraglottic musculature leads to deteriorating vocal function associated with aerodynamic incompetence of the glottic closure and to an unavoidable loss of epithelial pliability. Peretti *et al*. (2003) report similar results. They found that patients who underwent a type I or II excision have a quality of voice comparable to that of controls. By contrast, cordectomies including the entire vocal fold (type III/IV) and/or the anterior commisure (type V) showed significantly worse vocal scores.

14. Vocal outcome after radiation therapy

Radiotherapy resulted in improvement of the voice characteristics in at least 55% of patients. Deviant voice quality was mainly *negatively* affected in the older age group. Similarly, if stripping of the vocal fold was carried out for *initial diagnosis* (Verdonck-de Leeuw, 1999), the voice quality was poor following radiotherapy. Honocodeevar-Boltezar *et al*. (2000) reported that, most irradiated patients required a greater effort for voice production than usual. They also demonstrated significantly higher values for jitter, shimmer and noise-to-harmonic ratio than the healthy volunteers.

Evaluating the communicative suitability of voice (*i.e.*, situation-dependent adequacy of speech as judged by listeners) following radiotherapy for T1 glottic carcinoma, Van der Torn *et al*. (2002) found that, although suitability improved following radiotherapy, it did not approach the suitability of normal voices.

Assessing voice after radiotherapy and comparing it with patients with presbylaryngeal dysphonia, Berhman *et al*. (2001) concluded that patient perception and functional outcome of voice were similar for both groups, despite differences in aetiology of abnormal vocal fold behaviour. Therefore, radiotherapy in older individuals did not result in dysphonia any more than that caused by normal aging.

15. Benefit and risk issue with each modality of treatment for equitable voice outcome

Radiotherapy and laser surgery are established treatment modalities for T1 glottic carcinoma, although their comparative benefits are debated. The two main concerns are disease control and post-treatment voice quality. Both modalities offer a high probability of local control, therefore, voice quality may have an important role in decisions about treatment strategies (Sjögren, 2008). Introduction of endoscopic cordectomy and, particularly in the past decade, of partial resection prompts a detailed comparison among different types of cordectomy in relation to tumour extension and volume, expectations of the patient, and vocal results (Peretti, 2003).

A normal vocal outcome is usually obtained after type I and II cordectomies. Both perceptual and subjective evaluations show a clear trend toward postoperative reduction of the grade of dysphonia and of the severity of handicap in daily social and professional life. Therefore, other advantages of endoscopic excision must be discussed with the patient.

15.1. Benefits of laser excision

- Phonomicrosurgical resection preserves all treatment options, including further transoral resections.

Type I and II excisions can therefore be regarded as functionally adequate treatment, even for professional voice users.

- The cost of endoscopic excision is significantly lower than that of irradiation, and the patient avoids an increased burden of time and travel commitments.
- Laser excision is quick, with least morbidity and thus the patient can return to daily activity in a short space of time.

In cases of recurrence following laser excision, or in cases of second primary, the patient can opt out for radiotherapy.

15.2. Disadvantages of laser excision

- In contrast, resection of most of the vocal muscle and of the anterior commisure has been demonstrated to worsen postoperative voice in comparison with normal controls (Hirano, 1985; McGuirt, 1992; Zeitels, 2002; Peretti, 2003). Patients with type III, IV and V cordectomies often had a tendency toward a permanent dysphonia and an important subjective voice-related disability.
- As the depth of the resection margin extends to include the paraglottic musculature, there is further danger of aerodynamic and acoustic impairment. This leads to deteriorating vocal function with an inefficient glottal closure and a loss of epithelial pliability. These patients are optimal candidates for phonosurgical reconstruction in order to reduce the dysphonia resulting from such endoscopic treatments (Zeitels, 2002). A span of disease free interval between endoscopic cordectomy and the reconstructive procedure is always mandatory. Moreover, further treatments, both endoscopic and external approaches, are often necessary in order to obtain adequate vocal results; these treatments reduce patient compliance and the cost-effectiveness ratio.
- Exhaustive counselling is mandatory in patients with tumours requiring more extended cordectomies, for whom the disadvantages inherent to radiotherapy (duration of treatment, loss of time from work and social activities, higher rate of complications and partial preclusion of further conservative salvage surgery) could become acceptable (Peretti, 2003).

15.3. Benefits of radiotherapy

In patients who are unsuitable for endoscopic laser approach, radiotherapy is a viable option.

Radiotherapy also offers a useful palliation where recurrence is at an advanced stage due to non-compliance.

15.4. Risks of radiotherapy

- Radiotherapy treats *all* normal glottal tissue, including its saccular glands. The secretions provided by the mucociliary blanket that keeps the vocal folds moist and lubricated are lost due to gross nature of radiotherapy treatment.
- Radiotherapy induces fibrotic changes and impaired mucosal oscillation in both normal and cancerous tissues.
- The use of radiotherapy precludes its further use for tumour recurrence and for new primaries.

15.4.1. Evidence of vocal changes following radiotherapy to the head and neck for non-laryngeal tumours

- Radiotherapy used for head-and-neck pathology may result in inadvertent collateral damage to normal vocal folds, and there are a few studies reported in the literature. Hamdan (2009) reported a greater evidence of significant vocal alterations in these patients. A preliminary study by Fung *et al*. (2001) reported a group of non-laryngeal head and neck cancers treated with wide field irradiation with a significant vocal dysfunction due to changes secondary to the effect of radiation therapy on the vocal folds or the entire supraglottis.
- Hamdan *et al*. (2009) investigated the effects of xerostomia on vocal changes in patients following neck irradiation for non-laryngeal tumours, where glottic region was spared. The mean phonatory effort and GRBAS (Grade, Roughness, Breathiness, Aesthenicity, and Strain) in the treated group were significantly worse than in the control group. Xerostomia score correlated positively with all the GRBAS as well as with the phonatory effort. These findings suggest that vocal function can be affected by xerostomia secondary to radiotherapy.
- Another possible explanation for these vocal changes is the integrity of vocal tract on glottal behaviour. An important component of the layered structure is an *additional* layer of mucus – a 'mucus blanket' on the vibratory surface the vocal fold. This mucoserous secretions come from the glands located superiorly, inferiorly, anteriorly, and posteriorly to the edge of the membranous vocal fold (Hirano, 1993). The dependence of phonatory effort on hydration and the effect of removal of fluid on voice has been elucidated and studied by Verdolini *et al*. (1990). The vocal fold cannot vibrate if its surface is completely dry. Both systemic dehydration and local dryness can result in vocal changes and affect vocal function. Upper airway dryness secondary to mucosecretory changes and the increase in tissue viscosity is often present in patients with xerostomia. The propagation of the vocal signal along the vocal tract may be affected, resulting in the attenuation of the vocal resonant. Since the irradiation spared

the glottic region and no changes were observed in the irradiated patients in most of the acoustic parameters, it can be assumed that the vocal changes reported and perceived by the irradiated patients are partially due to the irradiation of the supraglottic region of the vocal tract (Hamdan, 2009).

16. Discussion

Although both external beam radiotherapy and endoscopic carbon dioxide laser excision of early glottic cancer will affect voice quality, it is difficult to compare them. The main problem of the few available comparative studies on functional outcome is that they are affected by selection bias by including only midcord lesions for laser surgery, large variations in follow-up periods as a consequence of retrospective designs and small-size sample. Another problem of the comparative studies is that the surgical arm did not include the most recent developments, some patients probably underwent more extensive resections than necessary, and others did not undergo surgical reconstruction of the glottal competency (Zeitels, 2002). In addition, the voice analysis methods lacked uniformity, reliability, and validity (Sjögren, 2008).

A complete voice assessment including perceptual, objective, and subjective evaluation is mandatory whenever a meaningful analysis of the pathological voice is to be accomplished. Meta-analyses of the results of voice treatments are generally limited and may even be impossible owing to the major diversity in the way functional outcomes are assessed. The European Laryngological Society (ELS) concluded in 2000 that there is no single voice analysis method that adequately describes voice function and that the assessment of the dysphonia needs to be multidimensional.

While acoustic, physiological and perceptual measurements are important parameters in assessing vocal function, they do not provide information about the patient's perception of their own voice quality. Given that voice quality, because of its potential impact on life quality, can be an important factor in the choice of treatment, it is imperative that this information be included when evaluating results. Not only should dysphonia be considered as a by-product of laryngeal intervention but also its effects on patients' life quality.

Sjögren *et al*. (2008) performed the first study with consecutive and comparable T1 lesions in a laser surgery group and a radiation group using a multidimensional assessment protocol based on ELS recommendations. They found that there is no statistical difference in the severity and type of voice dysfunction between both groups, although voice dysfunction profiles may be different, with voices of irradiated patients showing more roughness and the voices of laser surgery-treated patients being mainly breathy.

It is important to emphasize that the postsurgical voice outcome depends upon having a straight postoperative vocal fold for glottic closure and intact vibration from the contralateral vocal fold. Peretti *et al*. (2003) demonstrated that the mean VHI scores doubled when resection included more than the superficial vocalis muscle. Subepithelial and subligamental cordectomies are oncologically safe resections and have a quality of voice comparable to that of controls. Type I and II excisions can therefore be regarded as functionally adequate treatments, even for professional voice users. By contrast, with wider resections (type III, IV and V cordectomies), a concave neocord may form resulting in an aerodynamic glottic incompetence. In order to select the most appropriate treatment modality according to the patient's age, gender, compliance and professional activity, a detailed preoperative counselling concerning vocal outcome is recommended. After phonosurgical resection, patients who have lost paraglottic musculature may benefit from medialisation and augmentation procedures to re-establish glottic competence (see Part B of this chapter).

Other uncontrollable factors inherent to outcomes studies may be related to how patients view their voice after treatment. The sound of the voice, patient's expectations, cultural influences, personality, professional requirements, social activities, presence of gastro-oesophageal reflux, tobacco use, voice therapy and age may all affect patient perception of their voice and could not be assessed (Cohen, 2006).

Few patients have a 'normal' voice upon completing radiotherapy. Above all, there are a number of factors which indirectly influence the radiotherapy outcome. One (or both) vocal fold of these patients has undergone a surgical procedure in order to get a biopsy. There may have been an intense exposure to tobacco smoke. The disease is more prevalent in the older age group. All these factors have a negative influence on the voice quality (Verdonck, 1999).

Radiotherapy exposure is unavoidable to all normal glottal tissue, as well as saccular glands, which provide the mucus blanket that enhances vocal fold vibration. Post-radiotherapy videostroboscopy examination revealed that both normal and cancerous tissues reflect fibrotic changes and impaired mucosal oscillation (Lehman, 1988; Zeitels, 2002). Stoeckli *et al*. (2001) found, in a study of quality of life after treatment for early laryngeal carcinoma, that xerostomia related long-term effects of radiation are often underestimated (*i.e*., difficulties in swallowing solid food , dry mouth), although they have a substantially more detrimental effect on quality of life than voice function, which is generally dominates in the aftermath.

Part B: Augmentation methods to improve voice quality following laser management of early glottic carcinoma

17. Introduction

The voice quality following management of Tis and T1 glottic tumours remains comparable with both laser and radiotherapy management. However, unlike radiotherapy, the extent of resection in laser surgery has a significant impact on voice quality. As the extent of laser resection increases for larger tumours, voice quality is *less* likely to be comparable (Higgins, 2009).

The concept of phonosurgical management of early glottic cancer with ultrathin margins optimises both cure rate and voice quality. If glottal closure and aerodynamic efficiency are maintained, the plasticity of the vocal system can usually compensate for laser damage and results in a normal or near-normal conversational-level voice (Zeitels, 2002).

T1 glottic cancer patients who do not require resection deep to the vocal ligament (type I and II cordectomies) do not require reconstruction. On the other hand, major glottic incompetence is often encountered after total (type IV) and extended (type V) cordectomies and invariably results in poor vocal outcome. In such cases, voice therapy has only little impact on postoperative vocal outcome. Vocal fatigue is usual due to the wide glottal gap and stiff scar tissue. Even though the vast majority of patients accept significant limitations, a small number require some sort of phonosurgical treatment in order to regain a degree of vocal function.

Following laser resection, the restoration of the vocal function is based on re-establishing aerodynamic glottal competency. Concavity of the neocord following loss of mass is made up in to a straight edge by medialisation and augmentation techniques. If the contralateral vocal fold is anatomically intact, a conversationally normal or near-normal voice can be obtained in a majority of patients with early glottic cancer, by means of phonosurgical management as an integral part of resection regardless of the depth of the disease (Zeitels, 2002; Piazza, 2007). The following paragraphs provide an overview of important aspect of surgical excision of the vocal fold for early glottic cancers: an assessment of voice outcome and its augmentation, where indicated. In-depth coverage of various methods of augmentation procedures is beyond the scope of this work, but suffice it to say that no resection of cancer should be undertaken without considerations towards post-treatment follow up which should include, not just for verification of recurrence, but also for assessment and management of postoperative voice quality.

18. Voice restoration

18.1. Indications

A major glottic defect is not expected to lead to a useful voice in spite of a competent and prolonged voice therapy. However, the indication for phonosurgery should be based primarily on the patient's goals and requirements. In patients who are actively engaged in jobs, in particular, in jobs involving vocal communication, a good vocal performance is required. In such patients there will be a high motivating factor and counselling to undertake various phonosurgical procedures aimed at closing the glottic gap will be well received (Remacle 2001; 2006; Zeitels 2001; 2002).

18.2. Patient motivation

Although laryngeal cancer has correlation to voice dysfunction and patients' lifestyle, patients seldom relate quality of lifestyle to vocal dysfunction. The influence of quality of voice on the quality of life thus seems to be a minor one (Lopez, 2004). This was confirmed by Remacle *et al*., (2006) in a series of ten patients. Just 6.9% of all the cordectomy patients and 16.4% of total and extended cordectomy patients considered their voice as inadequate. From this point of view, self-report-symptom-questionnaires are convenient and consistent tools for assessing the importance of quality of voice to an individual following endoscopic cordectomy, and lead to an informed decision making for further surgical procedure (Rosen, 2004).

18.3. Videostroboscopy

Augmentation should be advised only if there is a glottic gap or a synechiae.

18.4. Contralateral vocal fold

A careful assessment of the functioning superficial lamina propria underlying the uninvolved epithelium by means of videostroboscopy allows the clinician to prognosticate the vocal outcome following resection and the reconstruction surgery. It is not unusual for patients with T1a glottic cancer to have abnormal contralateral mucosal waves at stroboscopy examination, as a result of long-term phonotrauma related to their life style, personality or vocation. Furthermore, phonation with a neoplastic lesion typically leads to hyperfunction, high subglottal pressures and increased collision trauma. Patients with early glottic cancer may have had atypia, in addition to the other long-term negative effects of smoking etc (Zeitels, 2002).

19. Timing for augmentation procedures

Most investigators agreed that there should be a trial of vocal rehabilitation with intensive voice therapy before laryngeal reconstruction is decided upon (Cavanagh, 2009). The studies quoted in this review used an interval of 6-13 months between the CO_2 surgical excision and the laryngeal reconstruction procedure. This time period allowed adequate healing, scar maturation, the verification of the absence of early recurrence, and the evaluation of the voice rehabilitation achieved by voice therapy.

20. Augmentation methods and results: review of literature (Table 2)

The concept of *phonosurgical* management of early glottic cancer puts together microsurgical approaches to enhance voice preservation with new reconstructive techniques that enable a majority of patients to achieve a normal conversational-level voice.

Zeitels *et al.* (2002) found in a prospective clinical trial that patients who did not require resection of muscle did not require phonosurgical reconstruction in the form of an augmentation or medialisation. However, deeper resections often resulted in an incomplete glottal closure and a tendency to generate higher airflows during phonation that led to a deteriorating vocal function associated with aerodynamic leakage and a loss of epithelial pliability. Such patients are optimal candidates for phonosurgical reconstruction. Once the neocord is healed, phonosurgical reconstruction may be carried out if the vocal edge is concave.

If there is adequate glottal tissue medial to the thyroid lamina, a Gore-tex medialisation laryngoplasty is performed. Gore-tex can be moulded in vivo to conform to the abnormal post-resection contours. The advantage of medialisation is that it can be done under local anaesthesia with intravenous sedation in order to allow phonatory feedback during the procedure.

When a large amount of paraglottic tissue is resected it is advantageous to perform an initial microlaryngoscopic lipoinjection in order to augment the paraglottic region with a subsequent implant medialisation if the glottal incompetence persists.

Anterior key hole aperture during adduction following anterior commisure tendon resection can be treated by an anterior laryngofissure under local anaesthesia and subluxation of the thyroid alae. Patients that underwent reconstruction medialisation subsequent to resection into the vocalis muscle displayed notable improvement in measures of average SPL, jitter, shimmer and HNR, maximum ranges for SPL and F0, subglottal pressure, and SPL-subglottal pressure ratio. A majority of patients attained normal values in many of the vocal function parameters during the final assessment.

Sittel *et al.* (2002) report a special technique of medialisation thyroplasty using autologous cartilage specifically adapted for vocal rehabilitation after laser resection, in which the superior rim of the thyroid cartilage of the resected side is exposed and a 1 x 2 cm piece of cartilage is harvested and reimplanted into a subperichondrial pouch created on the inner side of the thyroid alae. This technique is derived from a technique for external vocal fold medialisation described by Tucker (1987). Sittel *et al.* (2002) also reported that before the surgical voice rehabilitation the mean dysphonia index (which includes objective parameters as well as expert voice ratings and the patient's perception) of six individuals was 2.67. After the operation, the dysphonia index improved by 1.14, to an average of 1.53.

Table 2. Augmentation methods and results: review of literature

Author	*Patients*	*Stage*	*Speech therapy pre-/post-reconstruction*	*Techniques*	*Outcome measures*
Zeitels, 2002	13	T1a,T2a	Yes/Yes	Lipoinjection. Medialisation laryngoplasty. Subluxation of thyroid lamina	Average F0, SPL, Jitter, Shimmer, HNR, F0 range, aerodynamic measures
Sittel, 2002	6	T1a,T2	Yes/-	External vocal fold medialisation (cartilage)	GRB scale, videostroboscopy, phonetogram, MPT, dysphonia index
Su, 2005	15	?	?	Muscle transposition	?
Guven, 2006	10	T1,T2	-/-	Autologous fat injection	Stroboscopy, GRBAS, fundamental frequency, jitter, shimmer, HNR, MPT. Aspiration
Remacle, 2006	10		Yes/-	Medialisation thyroplasty (hydroxyapatite, Montgomery implant). Synechiae laser section and keel	VHI, Grade of GRBAS scale, MPT, phonation quotient, subglottic pressure, stroboscopy
Villaret, 2005	24	Tis, T1a	-/Yes	Immediate lipoinjection (Primary intracordal autologous fat injection)	GRBAS scale
Piazza, 2005	24	T1, T2	Yes/Yes	Medialisation thyroplasty (Gore-tex, Montgomery implant). Subluxation of thyroid lamina. Injection (Vox implant)	VHI, GRBAS scale, MPT, perturbation measures

Remacle *et al*. (2001, 2006) found that 6.9% of all cordectomy patients and 16.4% of the total and extended cordectomies patients consider their voice to be insufficient due to significant glottic gap or anterior synechiae. Medialisation thyroplasty using thyroid cartilage, titanium or hydroxyapatite implant was performed for glottic gaps, and a transoral placement of a laryngeal keel after laser-assisted section was performed for anterior synechiae. Thyroplasty is performed under general anaesthesia using a laryngeal mask airway that contains a small valve through which a fibre-optic laryngoscope can be passed in order to verify the appropriate position of the vocal fold inside a perfectly free glottic plane. The implants used are the Vocom hydroxyapatite implant (Smith-Nephew, Memphis, Tennessee) from Cummings and Flint, and the Montgomery implant The Vocom hydroxyapatite implant is used if the dissection cannot sufficiently be performed along the vocal fold level to permit the use of the Montgomery implant. Laser-assisted section of anterior synechiae and the placement of a laryngeal keel is performed transorally under subglottic jet-ventilation. Mitomycin-C is applied locally for two minutes after completion of the section. The keel is made in-house with a 0.2 mm thick sheet of silastic, and it is placed carefully between the two vocal folds at the level of the anterior commisure in close contact with the thyroid cartilage to minimise any recurrence of synechiae. After four weeks, the keel is removed and a new mitomycin-C application is done. The authors reported a hydroxyapatite implant extrusion eight months after coughing up the implant with a sudden deterioration of the voice. Four weeks after the healing of the wound, a Montgomery implant was placed, returning the voice quality to previous levels. A partial recurrence of the synechiae was observed in only one patient. Comparison between the individual or median preoperative and postoperative values of voice assessment showed a significant improvement, mainly for the self-evaluation scores of the VHI, G of GRBAS and the MPT. Stroboscopy showed improved or complete glottic closure, but it was typically irregular, with persistent vibratory asymmetry and vocal stiffness. Ventricular dysphonia usually persisted after medialisation.

Villaret *et al*. (2007) performed lipoinjection immediately after transmuscular (type III) cordectomies. The authors suggest immediate augmentation of the entire residual vocal fold because its normal viscoelastic features are not lost during the scarring process. Injected fat spreads along muscular fibres from the posterior injection site up to the anterior commisure. Patients who underwent immediate lipoinjection after transmuscular cordectomies experienced statistically significant improvement in G, B and A domains postoperatively, which was objectively measured by a panel of otolaryngologists and speech pathologists.

Guven *et al*. (2006) performed autologous fat injections in patients who had minimal dysphonia without symptoms of aspiration. Despite the resorption problem, the authors reported adequate results of voice and swallow functions, and believe that this technique is an easy, safe and cheap method for voice problems after laser or laryngofissure cordectomy defects.

Piazza *et al*. (2007) reported 24 patients, previously treated by type IV and V endoscopic cordectomies for T1 and T2 glottic cancer, which presented unsatisfactory vocal outcome in spite of intensive speech therapy. Patients were treated by medialisation thyroplasty with a Montgomery System Implant (two cases), Gore-tex strips (16 cases), Gore-tex associated with anterior commisure laryngoplasty as described by Zeitels in order to correct the anterior 'key hole' gap (three cases) and augmentation with Vox Implant injection (textured polydimethylsiloxane elastomers, three cases). Vox implants were preferred over Gore-Tex implants for the reduced amount of glottic incompetence to be corrected or the patient's desire to avoid the neck scar. Two endolaryngeal extrusions of the Montgomery implant were observed. The results reported in this study showed an improved glottic closure in videostroboscopy in 74% of patients. Comparison between the pre- and postoperative subjective, perceptual, and objective voice analysis showed a statistically significant improvement of the voice handicap index in each parameter of the GRBAS, and mean values of jitter, shimmer, noise to harmonic ratio and maximum phonation time. The authors did not specifically report the results of the use of Vox implants.

21. Discussion

Although glottic closure is a prerequisite for normal voice, many variables affect the functional outcome. One important variable is the morphology of the contralateral vocal fold. The results are surprisingly good with technically marginal approximations when the uninvolved vocal fold is intact. If the normal layered structure of the contralateral vocal fold is destroyed it is impossible to generate satisfactory vocal fold vibration. In the event, the voice will remain poor even after perfect augmentation injection or medialisation laryngoplasty (Ford, 1991).

Unlike irradiation, phonomicrosurgery avoids trauma to the layered microstructure of the uninvolved contralateral fold, which is ultimately the primary glottal sound source. Furthermore, the mucosal saccular glands are less affected by surgery. The laryngologist can precisely accommodate a micro-controlled excision to the three-dimensional characteristics of the vocal fold cancer. If glottal closure and aerodynamic efficiency are maintained, a normal or near normal voice can be achieved. In cases where there is no glottic gap, a difference in mass or tension of vocal folds does not generally play an important role in dysphonia (Tanabe, 1972). As the depth of the resection margin extends to include the paraglottic muscle, there is further danger of aerodynamic and acoustic impairment. Increasing the magnitude of resection, especially its depth, leads to deteriorating vocal function. These patients are optimal candidates for phonosurgical reconstruction (Zeitels, 2002). Most phonosurgical approaches should be followed by postoperative speech rehabilitation in order to optimise vocal outcome in the presence of the new laryngological configuration (Sittel, 2002; Zeitels, 2004).

In T1 and T2 glottic carcinoma patients, severe dysphonia persisted in only a small number of patients (Sittel, 2002; Remacle, 2006). This observation raises the question of what factors adversely influence the postoperative voice results. Koufman (1986) and Sittel (2002) consider that web formation as the most important negative factor, followed by preoperative radiotherapy. Dissection of the anterior commisure is much more damaging to the vocal quality than the removal of a large portion of the vocalis muscle. The individual pattern of scar formation is another key factor (Sittel, 2002). While in some cases, patients build up a pseudocord with effective glottic closure, in others, scar formation is minimal and the desired bulk effect does not close the glottic gap.

The indication for phonosurgery should be based primarily on the patient´s goals and requirements (Friederich, 1995). If a patient perceives his vocal function as adequate, no attempt should be made to direct him toward surgery, even if the phonatory function is objectively poor. Also, the request for surgical voice rehabilitation should be rejected if the criteria of eligibility are not fulfilled (Sittel, 2002). Self-report symptom questionnaires are consistent tools for assessing voice handicap as perceived by the patient. Hsiung *et al*. (2002) studied the correlation between the measurements obtained in the voice laboratory and the results of the VHI in dysphonic patients; a large discrepancy was detected between both assessments, leading to the conclusion that patient's own perception about his/her voice problem is not amenable to evaluation by objective measurements.

Dysphonia due to insufficient glottic closure can be treated very effectively by either approximation laryngoplasty or endolaryngeal augmentation. After an interval of 6-13 months to allow scar maturation, adequate healing and the verification of the absence of early recurrence, a reconstruction procedure may be proposed to the patient.

Laryngeal framework surgery is a substantial advance in phonosurgery because it avoids invasive modification of the vocal folds. Mediatisation laryngoplasty is particularly attractive because it is relatively easy to perform, induces little permanent changes in the tissues, and is potentially reversible. When surgeon and patient agree on medialisation laryngoplasty to improve vocal outcome, there are many different options available: thyroid cartilage, titanium, hydroxyapatite, silicone, Gore-tex and muscle transposition, each with its advantages and disadvantages. Lasting and stable vocal outcomes were noted for all patients who had undergone implantation. However, the extrusion of the implant was observed in one patient implanted with hydroxyapatite and in another, Piazza *et al*. (2007) reported two extrusions of Montgomery implant. Sittel *et al*. (2002) believe that approaching the paraglottic space from a superior direction is safer than excising a window in the thyroid cartilage, because the risk of entering the scarred endolarynx is minimised. There has not been significant concern about the fact that performing a window laryngoplasty compromises oncological management, by removing the barrier of the cartilage framework, to the extent of a potential future recurrence (Zeitels, 2002).

A variety of materials have been used in vocal fold injection. The material used for injection should be biocompatible, easily injectable, and biomechanically similar to the vocal fold. It should also be resistant to resorption and migration. Lipoinjection to decrease glottic incompetence was first used in postendoscopic cancer resection by Zeitels (2002). Chan and Titze (1998) reported that fat may be a satisfactory implantable material because of its viscoelastic properties and because it resembles normal mucosa. Fat autografts demonstrate tissue stability and long-term viability. In the long-term follow up, resorption has been reported in a wide range of 20-90% (Boyce, 1994). Despite this problem, lipoinjection remains an attractive alternative procedure for improving voice after laser or laryngofissure cordectomy defects; autologous fat is readily available, easy to harvest and safe, with minimal complication. The search for ideal material and procedure to restore the neocord is an active area of research (Guven, 2006). As Zeitels (2002) pointed out, subjective surgical observations revealed that it was easier to control the phonosurgical outcome with transcervical medialisation laryngoplasty than with lipoinjection, since there was phonatory feedback from the patient, enhanced intraoperative adjustability and precision, and no postoperative resorption.

If Broyle's ligament is excised, an anterior keyhole aperture can result during phonatory adduction that cannot be corrected by conventional medialisation, by vocal fold injection or thyroplasty. Zeitels *et al*. (2002) performed an anterior commisure laryngoplasty that corrected the anterior glottic gap. Marked improvements of the voice quality were observed after this procedure. As with thyroplasty, a minor criticism to this technique may be the alteration of the integrity of the laryngeal framework with possible opening of avenues for neoplastic spread from the paracommisural region into neck tissues (Piazza, 2007).

Phonosurgery and voice therapy have similar purposes: both are potential treatment options for patients with disordered voices, both are performed to alter voice quality and vocal efficiency permanently, and both are usually used to alter laryngeal physiology by decreasing or increasing glottal adduction so that the relatively automatic process of phonation can occur optimally. Reducing persistent vocal hyperfunction and giving exercises designed to enhance vocal fold entrainment are the goals of voice therapy that should be recommended to all patients preoperatively and postoperatively. Prephonosurgery voice therapy or preparatory therapy is directed to establish good vocal hygiene and, after operation, to establish the desired vocal techniques and behaviours. Postoperative therapy is designed to provide whatever additional adjustments are necessary to produce optimal voice quality and the patient's satisfaction (Ford, 1991).

In conclusion, the results of the studies on surgical correction of the voice quality after CO_2 laser resection of early glottic carcinoma clearly show how phonosurgical techniques permit significant amelioration of vocal outcome in specific, highly motivated subjects. Patient selection should follow strict guidelines with a recurrence-free follow-up interval of at least six months, the absence of pathological alterations in the resection area, a significant glottal gap and the express desire of the patient to have a better voice.

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MCQ – 12. Voice outcome after laser management of early glottic carcinoma

1. Assessment of voice recovery after treatment should be undertaken (tick true)
    a. Before six months
    b. After six months
    c. After six weeks
    d. After three months
    e. There is no hard and fast rule, and it should be tailor-made for each patient

2. GRBAS scale stands for (tick one)
    a. Grade, roughness, breathiness, aesthenicity and stress
    b. Grade, roughness, breaking voice, aesthenicity and strain
    c. Grade, roughness, breathiness, aesthenicity and strain
    d. Grade, roughness, breathlessness, aesthenicity and strain
    e. Gruff voice, rough voice, breathy voice, aesthenicity and strain

3. Maximum phonation time (tick one)
    a. Is a measure of aerodynamic efficiency
    b. Is a measure of phonation airflow
    c. Is a measure of vital capacity
    d. Is a measure of respiratory function
    e. None of the above

4. Phonatory outcome is assessed by
    a. Perceptual analysis using GRBAS scale
    b. Voice handicap index
    c. Videolaryngostroboscopy
    d. Spectrographic analysis
    e. All of the above

5. Voice quality is significantly affected by
    a. Excision of superficial lamina propria
    b. Excision of vocal ligament
    c. Excision of superficial lamina propria and vocal ligament
    d. Excision extended to include paraglottic muscle
    e. Excision extending to the anterior commissure

6. Radiotherapy and laser excision for T1 T2 vocal fold tumours
    a. Both give equitable oncological results
    b. Both give equitable functional (phonatory) results
    c. Radiotherapy is superior in controlling metastasis
    d. Laser excision prejudices further options in recurrent cases
    e. Laser excision is preferable in older age group

7. Decision to laser excision for T1 vocal fold is based on
    a. Patient being professional voice user
    b. Patient choice
    c. Encouraging literature reports

   d. Availability of surgical and hi tech expertise
   e. Perceived non-compliance for follow up

8. Following laser excision for cancer of vocal fold, the postoperative voice quality depends upon
   a. Extent of removal of paraglottic tissue
   b. State of the contralateral fold
   c. Patient motivation
   d. Excision of anterior commissure
   e. Preoperative radiotherapy

9. The one most important indication for postoperative voice augmentation procedures is
   a. Extent of the excision
   b. Poor objective results
   c. Glottic insufficiency seen on videolaryngoscopy
   d. Failure to improve following voice therapy
   e. Patient's own perception of poor voice quality

Chapter 13

An overview of the transoral management of the compromised laryngo-tracheal airway

V. Oswal

1. Introduction

The term laryngeal stenosis is used when the airway is sufficiently obstructed to cause symptoms of laboured breathing and stridor. Acutely obstructed airway needs emergency management and is beyond the scope of this work.

The aetiology of a progressive or *chronic* obstruction varies widely. It may be congenital or acquired. The acquired stenosis may be due to iatrogenic injury, a disease entity or idiopathic (Bodart *et al.*, 1998).

Stenotic synechiae, due to chemical or thermal burns, can occur in the larynx and may extend to the trachea (Szyfter *et al.*, 2009). Occasionally, fulminating inflammations or infections may result in synechiae as the resolution takes place (Loehrl and Smith, 2001).

Intentional or unintentional external trauma may lead to healing with a stenosed airway. Corrosives ingested intentionally or accidentally, will lead to necrosis of the mucosa and healing with granulations and fibrosis.

Anastomosis of the airway following excision via transcervical approach may lead to contraction and obstructed airway.

Tracheostomy site may heal with contraction leading to inward collapse of tracheal rings.

Tracheal stenosis may also be a result of external compression of the airway which leads to symptoms of stenosis, but are beyond the scope of this work.

The topic of laryngeal airway comprise is covered at three subsites, supraglottic, glottic and subglottic larynx. Since the condition does not follow strict anatomical sites, cervical trachea is also appropriately included under one heading of laryngo-tracheal stenosis (LTS). Lower airway stenosis and its endoscopic management is covered under Chapter 55.

An outpatient examination with a flexible or rigid endoscope remains pivotal to the diagnosis of the site, severity and the type of lesion. Computer tomography (CT) scans are the preferred imaging modality for assessing the lesion, particularly in respect of the caudal-cephalic extension. An examination under general anaesthesia is the definitive assessment tool for both mapping the lesion, assessing its nature and allows for histological sampling. Depending upon the severity of the obstruction it is always advisable to have a tracheostomy set available and ready to use. Patients should be fully informed of any potential adverse events as part of the consent procedure.

There are several management aims. The *primary* aim is to relieve the obstruction to the extent that effortless breathing is restored for activities of daily living. The *secondary* aims are to preserve the voice and safe swallowing, and where a tracheostomy is present, to decannulate.

Endoscopic management usually consists of releasing cuts into the lesion and dilatation. Excision or ablation should only be considered if a component of the stenosis does not exceed more than fifty percent of the airway obstruction. The procedures may have to be staged and stents may be necessary to prevent recurrence. Extensive stenoses and failed transoral management require transcervical

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approach. Laryngo-tracheal transplants and tissue engineered constructions have been used successfully and may make inroads in the ultimate management of desperate cases.

The CO_2 laser is the most useful laser in the management of benign airway stenosis. Most lesions are accessible by the 'line-of-sight' technique with the laser delivered via the microscope. Recently hollow flexible waveguides for the CO_2 laser have been introduced. Unfortunately their role is limited in the upper airway because of the large spot size and beam divergence problems. Their use is described in Chapter 59.

2. Scope of this chapter

This chapter covers the overview which is applicable to most conditions which result in compromised airway. Chapters 14-16, cover some distinct clinico-pathological entities, whereas Chapter 17 covers the use of laser in reducing the acute obstruction caused by malignant tumour, so that emergency tracheostomy could be avoided. Finally, chapters 18 and 19, cover the paediatric airway separately since paediatric airway stenosis often has differing pathophysiology to the adult patient and require alternative surgical approaches.

Trans-cervical management of LTS is covered only briefly for completeness.

3. Transoral laser surgery

Transoral laser surgery has the advantage of rapid restoration of a useful airway with minimum morbidity. The treatment does not have a cumulative dose effect and further laser usage is not contraindicated. In failed transoral cases, laser usage does not jeopardise tracheal resection and laryngotracheal reconstruction.

4. Functional anatomy of the laryngo-tracheal complex

The larynx is positioned between the tongue base and the trachea and separates the airway from the digestive tract. Laryngeal inlet is actively closed during swallowing. Surgical outcome for laryngeal conditions must take in to account preservation of the integrity of swallowing. If the laryngeal inlet fails to close during swallowing due to the disease or its management, then aspiration will occur, leading to serious consequences of aspiration pneumonia and even fatality.

The relationship of the larynx with the cervical vertebrae changes with growth. In infants, it lies at the level of the second or third cervical vertebrae. It descends to the adult position during the first few years of life to lie at the level of the fifth and sixth cervical vertebrae.

The male and female larynx differs little in size up until puberty. The adult larynx undergoes significant growth in both sexes, under the influence of the hormones responsible for secondary sexual characteristics. The growth is more marked in the male larynx.

The larynx is composed of several interconnected cartilages that are moved by muscles. The three unpaired laryngeal cartilages are the epiglottis, the thyroid and the cricoid cartilages and the three paired laryngeal cartilages are the arytenoid, the corniculate and the cuneiform cartilages. Cricoid is the only complete ring of cartilage in the airway. The larynx has four synovial joints. The paired cricothyroid joints are between the lateral aspect of the cricoid cartilage and the inferior horn of the thyroid cartilage and permit rotation of the thyroid cartilage on a horizontal axis. This has the effect of shortening the cricothyroid gap. The cricoarytenoid joints are present between the superior border of the lamina of the cricoid cartilages and the base of the arytenoid cartilages allowing for gliding and rotational movements of the arytenoid cartilages.

The principle function of the larynx is to protect the airway from aspiration during swallowing, but the larynx is also involved with phonation and the Valsalva manoeuvre. The narrowest part of the airway changes with growth. In the infants, it is the subglottis whereas in the adults, it is the glottis. The glottis commences at the apex of the laryngeal ventricle, however there is no universal agreement on its lower border. Some authorities consider it to be one centimetre below the most medial part (free edge) of the vocal fold while others consider it to extend up to five millimetres. The glottis has a paucity of lymphatics and spread of early glottis cancer to the lymph nodes of the neck is unusual. Upward extension of a malignant neoplasm begins to recruit the lymphatics of the supraglottic larynx above the apex of the laryngeal ventricle. However, downward extension of this disease will recruit subglottic lymphatics within two to three millimetres at the anterior commissure and seven to eight millimetres at the posterior commissure, hence the controversy. The subglottis extends to the lower border of the cricoid cartilage. The term laryngotracheal stenosis therefore includes injuries to the supraglottis, glottis, subglottis and *cervical* trachea.

The trachea is a tube that spans between the lower border of the cricoid cartilage of the larynx to the carina at the level of the sternal angle. At the carina, the trachea divides to give rise to the right and left main bronchi. In the adult, the trachea varies between 10-13 cm in length and is composed of approximately 20 C-shaped cartilaginous rings that are connected by fibrous bands and covered by respiratory mucosa. Posteriorly, the tracheal wall is composed of a flat fibro-muscular structure which spans between the arms of the C and contains the unpaired trachealis muscle. The trachealis constricts the trachea during a cough allowing the high velocity passage of air during a cough.

5. Gross *luminal* anatomy

Supraglottis consists of the epiglottis, aryepiglottic folds, ventricular folds, along with most of the arytenoids, and ends at a line drawn along the apex of the laryngeal ventricle.

Commencing at the apex of the laryngeal ventricle, the glottis includes the vocal folds, the vocal processes of the arytenoids and ends one centimetre below the most superior part of the vocal fold. The anterior glottis is lined with squamous epithelium, and the posterior glottis with respiratory epithelium which extends to the subglottis and trachea. Anterior commissure webbing and stenosis can result in both dysphonia and dyspnoea on exertion. Stenosis of the posterior glottis usually results in dyspnoea.

The subglottic airway is divided in to the proximal and the distal parts. The proximal part is bound by the thyroid cartilage anteriorly and by the posterior plate of the cricoid cartilage laterally and posteriorly. The distal part, the narrowest part of the airway, is formed by cricoid ring, the only totally unyielding structure in the airway. It is lined with ciliated columnar epithelium.

6. Prevention of laryngeal stenosis

There are certain considerations which will reduce the chances of stenosis in the first place, which are described here.

6.1. Intubation for non-laryngeal pathology

- The longer the intubation, the greater the risk of laryngotracheal stenosis.
- Do not use oversized ventilation tubes and exceed cuff pressures.
- Avoid movement of the tube against the tracheal wall by suitably anchoring it.
- Undue force, or oversized tubes, while intubating, may dislocate the arytenoids with ankylosis of the crico-arytenoid joint.

6. 2. Trans-oral laser surgery on laryngeal structures

Damage to the anterior and posterior commissures results in healing by scar tissue. The scar at the anterior commissure blunts the angle and forms a web. Scar at the posterior commissure anchors the arytenoids and prevents their abduction.

CO_2 laser energy is invisible. It may spread to the opposite cord at the anterior commissure, thus devitalising the tissue and creating raw surface on untreated side as well, during the healing process. When using the laser for recurrent respiratory papilloma at the anterior commissure, avoid the creation of opposing raw surfaces of the vocal fold by removing papilloma only on one side at any one time, followed by removal of the other side once the treated vocal fold has healed with healthy mucosa. Invisible reflections of the beam are also potential danger to the non-target tissue.

6.3. Anti-reflux regime

The extra-oesophageal reflux affects mainly the posterior part of the glottis and the subglottis. A preoperative and postoperative anti-reflux regime is now an accepted routine.

6.4. Antibiotics

Antibiotics are advised following laser airway surgery as infection could compromise the airway further. Sometimes antibiotic may be needed to treat bio-fouling of airway stents and following the insertion of laryngeal keels.

6.5. Steroids

Steroids are usually given during the induction phase of anaesthesia for airway surgery. They are also beneficial, injected intra-legionally, for inflammatory stenoses. The other role of steroids is in delaying impending airway obstruction, to allow time for securing a safe airway.

6.6. Mitomycin-C

Mitomycin-C is an antimetabolite. Its alkylating action inhibits cell division, protein synthesis and thus discourages fibroblast proliferation. It is applied topically with a small swab, following airway surgery, to inhibit recurrent granulation and scar tissue.

6.7. Avoid denuding cartilage

Preservation of mucosal lining helps healing with primary intention, avoiding granulations and subsequent fibrosis. Forcing ventilating bronchoscopes and bougies through a stenosed airway may lead to stripping of healthy mucosa. Pulmonary balloon dilation systems are preferable.

7. General aetiology of obstruction to airway

Airway obstruction results from a variety of aetiological factors.

The airway may be compromised by space occupying lesions such as malignant growths affecting the laryngeal structures. Emergency debulking to avoid tracheostomy is covered in Chapter 17. Non-malignant tumours usually cause breathlessness mainly on exertion. However, recurrent respiratory papillomatosis in children can cause significant airway obstruction, requiring a tracheostomy. The introduction of transoral laser surgery, described in Chapter 9, has dramatically changed the management of this debilitating condition.

Fibrosis and scarring of the larynx can occur in all the anatomical sites and result in a varying degree of stridor. Long term intubation trauma is the main cause of glottic, subglottic and tracheal stenosis. Intentional or accidental ingestion of corrosives and blunt or penetrating injury to the laryngeal framework may also result in stenosis. Iatrogenic trauma to recurrent laryngeal nerves during thyroid surgery results in unilateral or bilateral cord immobility, the latter leads to stridor.

Tracheal stenosis is covered in Chapter 55.

External compression may cause difficulty in breathing, Thyroid malignancy may spread intraluminally. These topics are outside the scope of this book.

7.1. Congenital laryngeal stenosis

For full coverage for the management of obstructed paediatric airway see chapters 18-19.

Congenital laryngeal stenosis results from failure of the laryngeal lumen to recanalise normally. However, about 95% of paediatric subglottic stenosis is acquired. Congenital subglottic stenosis is the third most common cause of congenital stridor after laryngomalacia and vocal fold paralysis. The normal diameter of the subglottic area is 4-4.5 mm at birth for a full term baby. A subglottic diameter of less than four mm is inadequate. In premature babies, the normal diameter is proportionately smaller.

Mild congenital subglottic stenosis may go unnoticed until superimposed by acquired stenosis following intubation trauma. Laryngomalacia is described in Chapter 19. The clinical findings range from minor fibrous bands to almost complete stenosis. There may be multiple level lesions, large vertical extensions, circumferential narrowing of the lumen, ankylosed joints and neuropathy. In long standing cases, there may be *tracheostomy-dependency* which results in failure to decannulate in spite of anatomically and physiologically adequate airway.

7.2. Acquired laryngeal stenosis

Iatrogenic trauma is the most common cause of acquired laryngeal stenosis in adults.

7.2.1. Intubation for non-laryngeal disease

Intubation for more than a week may lead to some degree of laryngeal stenosis. The most common site is subglottic, where unyielding cricoid cartilage forms a complete ring. Multiple intubations, repeated intubations and difficult intubations predispose formation of stenosis. Oversized tube, patient movement and extra-oesophageal reflux are further predisposing factors. Prolonged intubation leads to oedema, infection, avascular necrosis of mucosa, perichondritis and granulations with subsequent healing by fibrosis.

Intubation injury to the posterior commissure may lead to posterior glottic stenosis which may extend to the subglottis.

Eventful intubation may result in dislocation of arytenoid and subsequent fixation.

7.2.2. Laser surgery for laryngeal disease

Conduction of laser energy in to the tissue adjacent and deep to the target results in coagulation and death of the tissue. The healing is by fibrosis which leads to contraction and reduction of the airway.

The injury is more likely if spot size is larger, as was the case when CO_2 laser was first introduced in clinical practice in the late seventies (Spot size: 700 um). Even a single shot of a large spot size damaged the mucosa of both cords at the anterior commissure, due to the acute angulation of their attachment. Raw areas thus created led to substantial web formation, resulting in symptoms of breathlessness on exertion.

Conduction of laser energy should be anticipated and steps taken to adjust the energy accordingly. Small spot size available with newer and precision laser machines mostly removed the likelihood of such injury. High peak energy in superpulse mode (Chapter 2) and single shots introduce period of cooling of tissues between laser strikes.

Further precaution is taken by cutting through the papilloma and removing it only on one side at a time.

Overzealous laser removal of recurrent respiratory papilloma, and frequent laser usage in aggressive papillomatosis result in progressive fibrosis. In such cases, consideration should be given to the use of cold steel instruments, or powered instruments, rather than the laser.

Laser surgery of the arytenoids may lead to posterior glottic stenosis if interarytenoid tissue is damaged. Such injury can be avoided by placing a wet pledget over the interarytenoid tissue.

Bilatral recurrent nerve injury leads to bilateral abductor paralysis following thyroid surgery (Chapter 15).

7.3. Domestic or industrial fires

Thermal damage to the larynx results from inhalation of hot smoke in domestic or industrial fires. The most severe intraluminal injury is the anaesthetic tube ignition secondary to use of laser or diathermy. Surgical fire in the airway is devastating with fatal outcome. If the patient survives, there is gross oedema of the whole airway. The topic of airway fire is covered in Chapter 6.

7.4. Laryngotracheal reconstruction

In laryngeal reconstruction, an anastomotic site may constrict enough to result in stenosis.

7.5. Decanulated tracheostomy site

A shelf-like projection may protrude in to the lumen and the site may even show evidence of granuloma, or tracheomalacia.

7.6. Radiation

Radiation injury results from radio-induced lymphoedema due to lymphatic obstruction. The arytenoid mounds are covered with solid oedematous tissue causing dyspnoea and dysphagia.

7.7. Neurological aetiology

Iatrogenic injury to recurrent laryngeal nerve during thyroid surgery results in unilateral or bilateral recurrent laryngeal nerve paralysis. Endoscopic laser management is discussed in Chapter 15.

7.8. Inflammatory disease

Wegener's granuloma, laryngeal tuberculosis and sarcoidosis results in laryngeal obstruction. Laser management is described in Chapter 16. Laser usage in obstructive tropical diseases is covered in Chapter 56.

7.9. Acute obstruction due to malignant laryngeal disease

This topic is fully covered in Chapter 17.

7.10. External trauma

External laryngeal trauma is uncommon due to its recessed position with overhanging mandible. Intentional or accidental ingestion of corrosives produces extensive fibrosis which compromises the airway. Chapter 14 covers the topic of laryngeal trauma.

8. Presentation

8.1. Stridor

In all cases of obstruction to laryngo-tracheal airway, irrespective of the aetiology, the presenting symptom is laboured and noisy breathing: stridor. Initially, the symptoms may only be apparent on exertion.

Glottic and supraglottic obstruction causes *inspiratory* stridor, whereas subglottic and tracheal obstruction causes *biphasic (both inspiratory and* *expiratory)* stridor. Asthmatic stridor and stridor due to foreign body lodged in the tracheo-bronchial tree is typically *expiratory*.

8.2. Use of accessory muscles

The use of accessory respiratory muscles is evidenced by retraction of suprasternal notch and intercostal spaces. Nasal alae also show inspiratory indrawing in severe cases.

8.3. Cyanosis

Cyanosis is uncommon and denotes severe depletion of oxygen.

8.4. Tachypnoea and dyspnoea

Respiratory rate is increased with laboured breathing.

8.5. Hoarseness

Voice is hoarse and week when the obstruction involves glottis

8.6. Croup

In children, croup is a common symptom when inflammatory condition is superadded to the existing obstruction, particularly in the subglottic region.

8.7. Failure to thrive

In children, laryngomalacia is distinctly associated with complaints of weakness, loss of weight and general apathy.

9. Investigations

Flexible or rigid endoscopic examination is carried out to ascertain the anatomical landmarks, the site of obstruction and its severity. Stroboscopy is useful to obtain the baseline for phonatory assessment. Cephalo-caudal extension can only be ascertained with CT and MRI, and endoscopy under general anaesthesia, using 45- and 70-degree endoscopes. An examination of the whole laryngo-tracheo-bronchial area is mandatory. In tracheostomised patients, retrograde endoscopic examination of subglottis and direct examination of the trachea and bronchi is easily accomplished by passing a rigid endoscope through the tracheostoma.

Under general anaesthesia, the mobility of the cricoarytenoid joint is assessed by probing, it rules out ankylosed joint.

In tracheostomised patients, look for softening of tracheal rings which collapse inwards during laboured breathing. In such cases anchoring the rings to the subcutaneous tissue would stabilise the softened tissues.

From clinical viewpoint, it is necessary to ensure whether the lesion is affecting more than one anatomical region, *e.g.*, posterior glottic lesion may mask co-existing subglottic stenosis and would not relieve symptoms until both lesions are successfully treated.

Other investigations are aimed at assessment of patient's general condition to undergo surgery.

10. Management of acute obstruction

In acute cases, securing the airway takes the priority and may involve intubation or tracheostomy. Further discussion is beyond the scope of the present work. Laser debulking for malignant obstruction is covered in Chapter 17.

11. Management of chronic obstruction

Initial management consists of placing suitable support under the neck in order to avoid flexion, supplemental oxygen or oxygen-helium mixture, and intubation if required. For severe obstruction, if not already carried out at the primary referral centre, tracheostomy is necessary to allow investigations and planning of management. A possibility of multistage procedure should be discussed and the patient counselled accordingly.

The aim is to restore adequate airway, voice and swallowing. Broadly, the following options are available:

- Wait and watch;
- Intralesional steroids and repeated dilatations;
- Endoscopic transoral management;
- Transcervical approach for open surgical management.

11.1. Wait and watch

Wait and watch policy is usually applicable for cases of mild symptoms resulting from, *e.g.*, laryngomalacia.

11.2. Intralesional steroids and repeated dilatations

In minor cases of thin fibrous stenosis, a functionally adequate airway may be obtained.

11.3. Transoral endoscopic laser management

Transoral endoscopic laser management is quick, and is associated with very little morbidity. When laser is used, the surgery is bloodless and there is no oedema. Patients are able to go home the same day after a period of observation. In cases of co-morbidity, a short hospital in-patient stay is necessary. The detail surgical steps are described later.

11.4. Transcervical management

When caudal-cephalic extension is more than two centimetres, the external open surgical management may be the only option available. Similarly, a failed transoral management after repeated attempts also requires external approach. The surgery consists of excision of the stenosed part and anastomosis. A brief discussion is included in Chapter 16.

12. Preparation for transoral laser surgical intervention

The general preparation for transoral laser surgery is described in Chapter 7.

13. Team, equipment and instrumentation

Airway obstruction requires a dedicated team effort. Every member of the team has his/her own role to play. In addition, the members should be able to anticipate the steps involved so that their work complements the surgery. In addition to the normal laryngeal instruments, long-handled instruments are necessary to undertake subglottic procedures. A tracheostomy set should always be available and ready for use, in severely obstructed cases.

14. Anaesthesia/tubeless anaesthesia

Anaesthetic colleagues form an important integral part of the team. They should be informed of the nature and extent of pathology and the management strategy. The discussion can be much more fruitful if imaging and outpatient video recording are studied together.

15. Suitable lasers/unsuitable lasers

CO_2 laser is ideal and remains a laser of choice for laryngeal work. In its free beam mode, it must be used in the line of target. CO_2 laser cannot be delivered via optical fibre. Waveguides are available; they are for single use and can be cost prohibitive. The latest wave-guide technology is described in Chapter 59.

For tracheal work, fibre transmissible KTP and diode lasers are useful.

In free-beam mode, Nd:YAG laser has much scatter and deep penetration. Its use in the larynx is not recommended.

Pulse dye lasers and pulsed KTP laser wavelengths are selectively absorbed by haemoglobin in blood resulting in coagulation of the blood vessels and avascular necrosis of the tissue. Their use is described in Chapter 60.

16. Laser surgical strategy

While laser has made great advances in the transoral management of a variety of laryngeal pathology, it should be used with care and awareness of the potential deep thermal spread of its energy. Some rule of thumb points are worth remembering:

- Use single shots rather than continuous strikes, this allows cooling of tissues and disperses heat;
- Use focused beam;
- Remove char since char burns at higher temperature than water and, in the process, heats up the underlying tissue;
- Nd:YAG laser, with its inherent scatter within the tissue is most *unsuitable*;
- Preserve as much mucosa as possible. If possible, raise the flap and remove tissue submucosally. Re-position the flap and use fibrin glue to retain it *in situ*;
- Excise the issue rather than vaporise it, so that delineation between the normal and the scar tissue

is clearly visible. Preservation of the free edge of the vocal fold and the vibratory margin helps phonatory outcome;

- In oedematous tissue, submucous delivery of laser has an effect of shrinking the bulk;
- Use pledgets soaked in adrenaline 1:1000 to control bleeding. Long-handled suction diathermy is useful to control bleeding from larger sized vessels.

17. Postoperative monitoring

Ideally, the patient should be extubated in the theatre to ensure that the breathing is unobstructed. A team conversant with airway management forms a backbone of surgery for the obstructed airway.

Post-operative care should be in an adult or paediatric intensive care unit as appropriate.

If the endotracheal tube is left *in situ* for a period of time, then steroids (dexamethasone 1 mg/kg/d) should be given a day before planned extubation, and continued for 48-72 hours afterwards.

A competent member of the team should always be available at the time of extubation so that immediate re-intubation can be undertaken if necessary.

In cases where tracheostomy existed prior to the operation, a possibility of tracheostomy dependency must be kept in mind.

Depending on the nature of the surgical procedure, swallowing is commenced under the supervision of the speech-and-swallowing pathologist

18. Criteria of success

Restoration of airway has a three-fold aim. First and the foremost, an adequate airway is essential so that patients can undertake their daily activity without getting out of breath. Secondly, a good phonatory outcome is desirable, although these two aims are contradictory in cases of arytenoid surgery for bilateral abductor palsy. Finally, swallowing should be achieved without aspiration.

Where the patient had tracheostomy prior to the transoral procedure, a successful decannulation is certainly a measure of restoration of an adequate airway.

19. Follow-up care

Initial success may be short lived with recurrence of symptoms. In such cases, careful consideration should be given to measures ranging from frequent dilatation, repeat transoral procedure and transcervical approach.

20. Patient counselling

Management of airway obstruction is complex. At times, staged procedures are required. Their planning should be undertaken right at the outset, and patients counselled accordingly. Cost consideration, periods of absence from schooling or jobs, loss of income are some of the issues of relevance to the patients. Surgical procedures require a skilled team, hi tech equipment and dedication. Small centres may not have all the requisites, and patients may have to travel distances or even travel abroad. It will then be necessary to tailor-make the surgical procedure for that particular patient, and may not be exactly ideal.

21. Risk – benefit issues for *transoral* endoscopic laser surgery

In suitable cases, transoral surgery has resulted in much patient comfort, shortened hospital in-patient stay, day surgery, and reduction in costs. There is much less morbidity and tracheostomy is rarely required even after prolonged laser surgical procedure.

Adequate exposure is always necessary and may not be possible due to full denture, short neck, etc., it may be necessary to reposition the laryngoscope frequently, adding to the surgical time. Careful evaluation of the dental state of the patient should be undertaken and a possibility of damage should be mentioned.

The single most common risk factor is recurrence of fibrotic tissue after an apparently successful laser surgery for webs and stenoses. A full discussion with the patient is necessary so that a recurrence is not seen as failed surgical procedure.

Anaesthetic tube ignition and other surgical fires should never pose a risk, since the measures to avoid these mishaps are now well documented in the literature. All surgical fires are non-defensible.

Laser debulking for malignant laryngeal lesion poses a special risk. A dedicated team is essential for a successful outcome of this potentially fatal condition. If the team is not available for whatever reason, then serious consideration should be given to restoring the airway by an age-old method of emergency tracheostomy. Laser debulking should never be undertaken unless a tracheostomy set is immediately available and in a ready state.

22. Discussion

The management of laryngo-tracheal strictures remains a challenging problem for the otolaryngologist due to the following factors:

22.1. Nature of pathology

Airway obstruction is a serious condition with potential to fatality. Its successful management requires a high level of skill acquisition, both by the laser surgeon and the team. Laser management should be undertaken by surgeons who are conversant in dealing with conventional methods, should laser procedure be aborted for a number of reasons such as failure to intubate, failure of equipment, inadequate access and so on.

22.2. Anatomical accessibility (subglottic lesions, tracheal lesions)

Long neck, short neck, full denture, cervical spondylosis, etc.

22.3. Socio-economic factors

In common with many other conditions, laryngo-tracheal stenosis is common in lower social strata.

22.4. Rate of recurrence

Irrespective of skilfully performed perfect surgical procedure, there are bound to be failures. However, the rate of failures can be minimised if such procedures are undertaken in a dedicated setting with hi tech equipment and experienced team.

22.5. Multistage management strategy

Where possible a staged surgery should be carried out, so that preservation of the voice is optimised.

23. Training and courses

Management of obstructed airway, particularly in children, neonates and premature babies requires a degree of sophistication which can only be achieved by attending well-established and reputable training courses, and peer supervision. A critical appraisal and self audit goes a long way to improve on the results.

MCQ – 13. An overview of the transoral management of the compromised laryngo-tracheal airway

1. Laryngeal stenosis is a term used
    a. When its lumen is reduced due to the structures of the laryngeal framework encroach in to it
    b. When there is stricture in the mucosal wall
    c. When there is external compression reducing the lumen
    d. The normal diameter of the laryngeal lumen is reduced irrespective of the cause
    e. All of the above

2. The narrowest part of the laryngeal airway
    a. Is the subglottis
    b. Is the glottis
    c. Is the distal part of the subglottis formed by the cricoid ring
    d. Changes with age, in children it is subglottis, in adults it is the glottis
    e. Changes with age, in children it is glottis, in adults it is the subglottis

3. The term laryngo-tracheal stenosis includes stenosis of
    a. The larynx and the trachea up to carina
    b. The larynx and the cervical trachea
    c. The larynx and the tracheo-bronchial tree
    d. The supraglottis, glottis, subglottis and trachea up to the suprahyoid notch

4. The commonest aetiology of subglottic stenosis is
    a. Laser surgery on anterior commissure extending in to the subglottis
    b. Prolonged intubation for non-laryngeal conditions
    c. Cervical injury involving cricoid ring
    d. Smoke inhalation from domestic or industrial fires
    e. Congenital

5. Intubation related stenosis is due to
    a. Crash intubation
    b. Prolonged intubation
    c. Dislocation of arytenoids during intubation
    d. Pressure necrosis due to the use of oversize tube
    e. All of the above

6. The normal diameter of the subglottis in a full term baby is
    a. Less than 5 mm
    b. More than 5 mm
    c. 3 mm
    d. 3.5 mm
    e. 4 – 4.5 mm

7. Common aetiological factors which may result in the posterior glottic stenosis are
    a. Reflux
    b. Congenital
    c. Subglottic stenosis extending on to the under surface of the posterior commissure
    d. Laser trauma to interarytenoid muscles
    e. Prolonged intubation

8. Narrowed laryngeal airway results in the following
    a. Stridor
    b. Dysphagia
    c. Dyspnoea
    d. Dysphonia
    e. Symptoms depend on the site of the lesion, its nature and its severity

9. Subglottic stenosis causes
    a. A wheeze
    b. An inspiratory stridor
    c. An expiratory stridor
    d. A biphasic stridor
    e. Hoarseness

10. The most important investigation to assess the laryngeal stenosis is
    a. CT scan
    b. MRI
    c. Airflow measurements
    d. Examination under general anaesthesia with spontaneous breathing
    e. Stroboscopic examination of the movements of the vocal fold

11. Transoral management is contraindicated
    a. In obese patients
    b. In stenoses exceeding three cms
    c. In stenoses exceeding two cms
    d. In circumferential stenoses
    e. In multilevel stenoses

12. Initial treatment should be
    a. Intralesional steroids
    b. Laser excision
    c. Repeated dilatation
    d. Laser excision and Mitomycin-C
    e. Tailor made to the individual lesion

13. The single most common risk factor in the transoral laser management of laryngeal stenosis is
    a. Airway fire
    b. Recurrence of stenosis
    c. Need for tracheostomy
    d. Need for multi-stage procedures
    e. Postoperative oedema

Chapter 14

Laryngeal trauma

S. Gandhi and G. Sandhu

1. Introduction

Laryngeal trauma can occur due to external anterior cervical injuries, or endolaryngeally. External laryngeal trauma is uncommon due to its recessed position with overhanging mandible, and a rigid vertebral support in the back. Trauma from intubation and ventilation tubes is discussed in Chapter 15. Iatrogenic injury to recurrent laryngeal nerve during thyroid surgery results in unilateral or bilateral recurrent laryngeal nerve paralysis. Description of homicidal or suicidal penetrating injuries of the larynx are beyond the scope of this work.

2. External trauma

The commonest cause of blunt laryngeal injury is through motor vehicle accidents where the neck strikes the steering wheel during rapid deceleration. Clothesline injuries can also results in blunt trauma and may lead to laryngeal fracture or cricotracheal separation. Farmhands who use powered bikes may not see a boundary barbed wire, and unwittingly drive in to it with resultant neck and laryngeal injury. Punch-up fights, manual strangulation and sports injuries are other rare causes.

External neck trauma may result in injuries to the laryngeal framework and also the intraluminal structures. The extent of the injury is dependent upon the severity of the trauma as well as its anatomical location on the front of the neck. Hyoid bone and thyroid cartilage may be fractured, however, commuted fractures are uncommon as cartilagenous fragments tend to move inwards within the airway. Injury to the cricothyroid can result in cricothroid joint dislocation when the inferior cornu of the thyroid cartilage is pushed posteriorly. This can also produce an injury to the recurrent laryngeal nerve which passes closely behind this joint.

Within the lumen of the larynx, a variety of structural damage is encountered. It ranges from bruising, haematomas, mucosal tears, and detachment of the epiglottis and the vocal folds. A degree of airway obstruction is inevitable. There may also be an associated impairment of vocal cord function either through a concurrent recurrent laryngeal nerve injury or damage in or around the cricoarytenoid joint.

2.1. Presentation

Patients present with a range of symptoms. In its most acute form, there is stridor and dyspnoea which needs emergency management of the airway. Less severe cases present with hoarseness, odynophonia and odynophagia. Palpation of the neck may reveal subcutaneous emphysema, loss of landmarks and tenderness. Neurological injuries, especially where there is pharyngeal trauma, may result in aspiration.

2.2. Algorithm of management of trauma

Laryngeal trauma can be life threatening. Even if the patient seems stable at presentation, there is always the risk of airway obstruction in the hours to come, from oedema, haematomas, and infection associated

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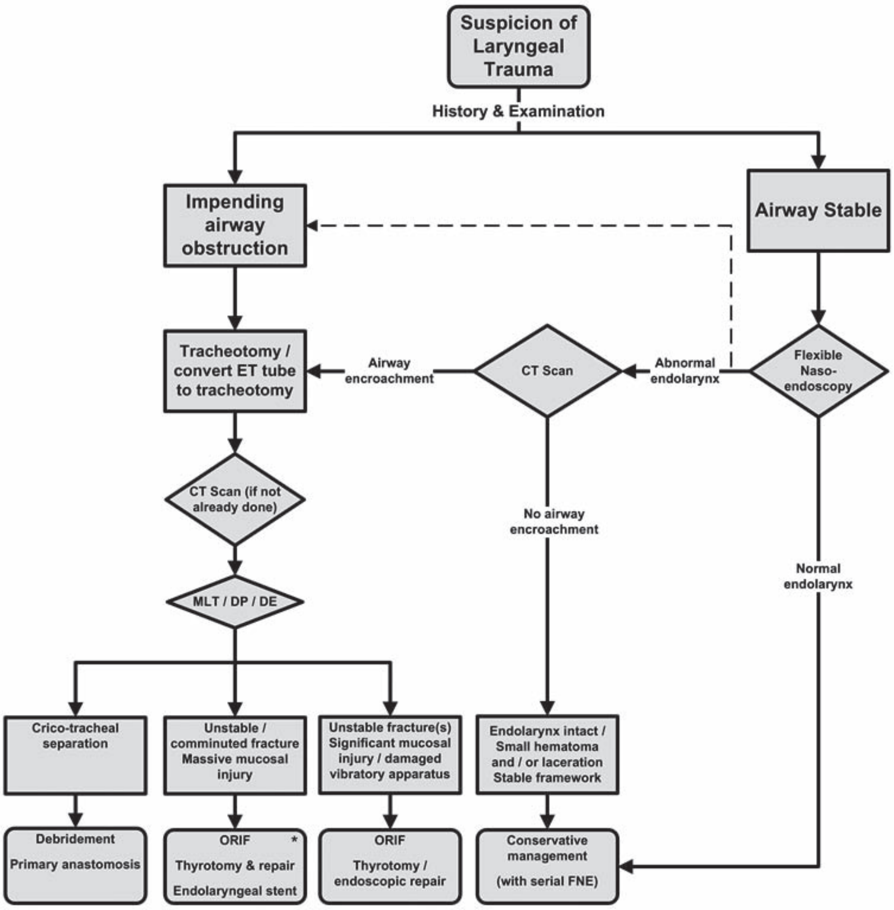
Table 1. Laryngeal trauma management protocol


Suspicion of Laryngeal Trauma
History & Examination
Impending airway obstruction
Airway Stable
Tracheotomy / convert ET tube to tracheotomy
Airway encroachment
CT Scan
Abnormal endolarynx
Flexible Naso-endoscopy
CT Scan (if not already done)
No airway encroachment
Normal endolarynx
MLT / DP / DE
Crico-tracheal separation
Unstable / comminuted fracture Massive mucosal injury
Unstable fracture(s) Significant mucosal injury / damaged vibratory apparatus
Endolarynx intact / Small hematoma and / or laceration Stable framework
Debridement
Primary anastomosis
ORIF *
Thyrotomy & repair
Endolaryngeal stent
ORIF
Thyrotomy / endoscopic repair
Conservative management
(with serial FNE)

MLT / **DP** / **DE**: Microlaryngoscopy & Tracheoscopy / Direct Pharyngoscopy / Direct Esophagoscopy.
ORIF: Open Reduction & Internal Fixation **FNE**: Flexible Naso-Endoscopy **CT**: Computed Tomography.

with the laryngeal injury. Even when patients seem out of danger with respect to airway compromise there may be long-term effects due to fibrosis and airway stenosis. These patients therefore need a systematic approach. The algorithm in Table 1 outlines the approach to the management of laryngeal trauma (Sandhu, 2010).

2.3. Emergency management

If there is impending airway obstruction, the patient should have a surgical tracheostomy fashioned and if an endotracheal tube is in place this should be converted to a tracheostomy as a matter of priority to minimise damage and scarring of the glottis. If the patient is stable, the assessment is carried out as follows.

2.4. Assessment of endolaryngeal injury

2.4.1. Diagnostic and therapeutic endoscopy

Flexible nasal endoscopy is carried out to assess injury to the laryngeal mucosa, the vibratory margin and laryngotracheal complex and can be performed serially to monitor the patient's progress.

2.4.1.1. Supraglottis

Anatomical distortion of the supraglottis may be seen after external injuries. Mucosal injury can lead to supraglottic stenosis, between the two ventricular folds. In cases of dislocation of arytenoids, the aryepiglottic folds may collapse during inspiration, the appearance is similar to that of laryngomalacia. Circumferential supraglottic scarring can be seen in delayed presentation of external laryngeal trauma.

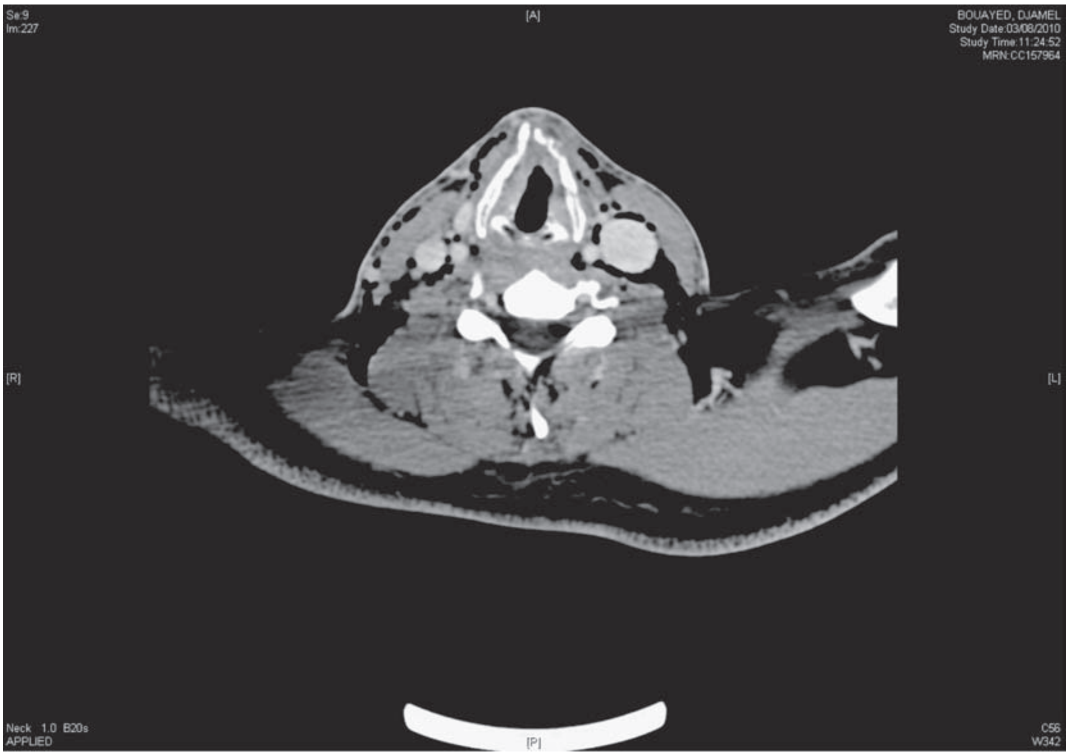


Fig 1. CT scan showing fractured thyroid cartilage and distorted endolaryngeal anatomy.

2.4.1.2. Glottis

Tears and loss of vocal fold tissue due to external injury may present with dysphonia and stridor. Resorption of vocal cord haematoma may lead to sulcus vocalis.

2.4.1.3. Subglottis

Persistent haematomas in the subglottis can produce sloughing and granulation which may lead to scar formation, contracture and subglottic stenosis if not evacuated within the first few days.

2.4.2. Computed tomography

Once the airway is secured, computed tomography is undertaken to assess the integrity of the laryngotracheal airway (Fig. 1).

2.5. Conservative management of laryngeal trauma

Patients found to have minimal endolaryngeal injury on flexible endoscopy and a stable laryngeal framework with a patent airway can be managed conservatively as follows:

- Minimum of 24 hours observation on the High Dependency Unit;
- Regular cardiorespiratory observations;
- Serial flexible nasal endoscopy;
- Patient is nursed upright to reduce further oedema;
- Corticosteroids;
- Broad-spectrum antibiotics;
- Proton-pump inhibitors.

2.6. Follow up

The final outcome of laryngeal trauma is not apparent in the immediate post-trauma period and a long-term follow up, with repeated airway assessment is necessary to identify and treat the sequel. Delayed findings may be in the form of fibrosis and stenosis.

2.7. Endoscopic laser management

Cases presenting with a compromised airway require urgent assessment and the airway needs to be made safe (see table 1). Once the airway is safe, endoscopic examination under general anaesthesia is required at the earliest opportunity to allow assessment of the injury and to carry out repairs. Haematomas can be incised and evacuated and mucosa can be trimmed or sutured back. The laser, delivered endoscopically, is useful in managing granulation and scar tissue that forms as a part of wound healing. The carbon dioxide laser can be delivered via the microscope, using a line-of-sight technique, and the carbon dioxide laser-fibre system is used for areas that are otherwise difficult to access. Radiate cuts should be made into areas of stenosis and bands of scar to allow effective airway dilatation.

In cases of crico-arytenoid dislocation, where the arytenoid prolaspes into the airway, the obstructing component of the arytenoids cartilage can be laser ablated.

Unilateral paralysis of the cord may require augmentation to restore phonation.

Bilateral abductor paralysis needs lateralisation of the vocal fold, or unilateral cordectomy. Laser surgical techniques are similar to those described for various benign lesions and will not be repeated here. Management of laryngeal stenosis is covered in detail in Chapter 16. The following paragraphs give an overview of the management.

2.8. Airway obstruction

The management depends on the findings. Generally, for stenosed ventricular bands, transoral CO_2 Laser excision, undertaken in two stages, is the treatment of choice. Mitomycin-C is used topically following resection. Restenosis is not uncommon in the supraglottis. Follow-up laryngoscopy and removal of slough within a week discourages restenosis.

Circumferential narrowing of supraglottis poses a challenge. Partial epiglottectomy may help in these cases. Ary-epiglottopexy, as in cases of laryngomalacia, is useful for patients presenting with a lax supraglottis and collapsing aryepiglottic tissues.

Glottic incompetence due to loss of vocal fold tissue is compensated by endoscopic tissue fillers or by medialisation thyroplasty.

3. Endolaryngeal trauma

Endolaryngeal trauma occurs in a variety of ways. The most common trauma is iatrogenic: intubation injury. Improper use of the laser is another iatrogenic cause.

Accidental or suicidal ingestion of corrosives leads to superficial or deep chemical burns of the mucosa.

Management of most sequelae resulting from endolaryngeal injury has been covered in other chapters, this chapter provides only an overview.

3.1. Intubation injury and its laser management

Approximately 10% of patients have demonstrable laryngeal injuries one day following short-term intubation for surgery (Heidegger *et al*., 2007) With longer-term intubation and mechanical ventilation for critical illness, the incidence of laryngotracheal injuries approaches 90%, with long-term sequale occurring in 11% of patients (Esteller-More *et al*., 2007). The incidence of post-intubation laryngotracheal stenosis requiring surgical correction is one in 204,000 adults (Nouraei *et al*., 2007) and 4.9 in 100,000 in children (Leung *et al*., 2007) per year.

Crash intubation, carried out to restore an obstructed airway may cause mucosal tears and crico-arytenoid dislocations. In *elective* intubation, a mucosal tear is unlikely, and the most common injury is cricothyroid dislocation. Mucosal tears usually do not require active management. Cricothyroid dislocation can result in protrusion of arytenoid into the lumen, causing inspiratory obstruction. Protruding portions of the cartilage can be easily vaporised with improvement in the airway.

Prolonged tracheal intubation causes mucosal damage due to pressure necrosis and perichondritis. An intubation granuloma is a well-recognised entity, following prolonged intubation. It usually forms on the medial aspect of the arytenoids or its vocal process and may be bilateral. Granulomas can be removed with cold instruments or laser. Detail management is described in Chapter 15.

Ischaemic necrosis of the airway mucosa and cartilage usually occurs where there has been excessive cuff pressure in the endotracheal tube over a prolonged period. At extubation there may be granulation present at this site. In some cases, if left untreated, this may lead to stenosis from scarring and contracture. The symptoms of breathlessness may not appear for several weeks after extubation. The patient may also have dysphonia or a chronic cough. Management is difficult, it is described in Chapter 16.

3.2. Webs and scarring due to collateral damage during laser surgery: prevention and management

Laser energy ablates the tissue by thermal vaporisation. While most of the energy is spent in vaporisation, residual energy is conducted in to the deeper tissue. Here, it causes coagulation of the cell protein. The tissue damage is repaired with fibrosis and contracture.

In the anterior commissure, if apposing surfaces of the vocal folds are denuded at the same time, the healing with fibrous tissue leads to blunting of the angle, which may lead to web formation. Anterior glottic webs, if sufficiently large, encroach on the airway, resulting in breathlessness, particularly on exertion. Division of the web with temporary insertion of a keel or stent will often prevent recurrence.

In the surgery of the papilloma at the anterior commissure, a cut is made in the centre of the papilloma and only one side is removed at any one time. This staging avoids creating bilateral raw areas and eliminates the risk of anterior glottis webbing. Some surgeons believe that aggressive papillomatosis requiring frequent interventions should be tackled with cold instrumentation which does not have an associated thermal injury.

Inadvertent thermal damage to the vocal ligament may result in scar formation and the clinical appearance is one of sulcus vocalis. Loss of a vibratory layer leads to dysphonia. Injection of saline deep into the vocal fold acts as a heat sink and protects the underlying normal tissue. Collateral thermal damage is minimised by following phonosurgical techniques, described in Chapter 10.

Collateral thermal damage is sometimes inevitable, particularly when the laser is used to remove a malignant growth. Loss of tissue leads to glottic insufficiency. Medialisation thyroplasty or injection laryngoplasty may be undertaken after ensuring that there is no recurrence. Some surgeons prefer to undertake injection thyroplasy routinely at the end of the excision.

In laser arytenoidectomy, if the laser energy spreads to the interarytenoid area, it will cause damage to the interarytenoid muscle and results in fibrosis between the two vocal folds. Such injury can easily be prevented by covering the interarytenoid area with wet pledgets.

3.3. Ingestion of corrosive agents

Caustic and thermal injuries can also cause laryngeal and tracheal airway strictures, the severity of which is reported to be greater than those associated with post-intubation laryngotracheal stenosis, with dysphonia being present in as many as 70% of patients.

Injury to the larynx occurs in 6% of inhalation burns patients, and in 40% of patients with caustic ingestion. Both injuries, if not recognised and treated promptly, can lead to severe long-term complications.

Ingestion of corrosive agents causes a deep chemical injury which produces profound inflammatory oedema and airway obstruction requiring emergency measures to restore the airway. The damaged mucosa undergoes necrosis and sloughs away. Healing is by granulations which eventually leads to fibrosis and airway compromise.

Ingestion of corrosives in children is accidental. In adults it may be intentional, to commit suicide. Chemical burns in adults are often deep due to a large quantity of ingested corrosive.

Fibrosis usually occurs in the oropharynx and supraglottis. The glottis is often spared, since it is relatively protected during swallowing.

Laser excision of fibrous tissue usually restores the airway and the swallowing. However, in extensive burns, the results of laser surgery may be disappointing since excised fibrous tissue is replaced by even more fibrous tissue.

Further management is beyond the scope of this work.

3.4. Inhalation of smoke

Inhalation of smoke from domestic or industrial fires leads to gross mucosal oedema. Healing is by fibrosis. Laser management is similar to that described above.

3.5. Lymphoedema following radiotherapy

Radiotherapy may lead to gross lymphatic obstruction with lymphoedema of the arytenoids mounds. Dysphonia, difficulty in breathing and dysphagia can be helped by laser vaporisation of the solid tissue covering the arytenoids.

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MCQ – 14. Laryngeal trauma

1. Acute airway obstruction following laryngeal trauma requires
   a. Observation in ITU
   b. Tracheostomy
   c. Intubation
   d. Laryngectomy
   e. Assessment followed by appropriate management

2. Irrespective of aetiology and severity of laryngeal trauma every case requires
   a. Intubation or tracheostomy in case there is delayed airway compromise
   b. Minimum of 24 hours observation on the High Dependency Unit
   c. Nasogastric tube feeding to prevent aspiration
   d. Corticosteroids
   e. Broad-spectrum antibiotics

3. Life threatening condition is suspected in the presence of
   a. Stridor
   b. Dyspnoea
   c. Aspiration
   d. Odynophonia
   e. Odynophagia

4. Commuted fractures of laryngeal cartilages is rare because of the
   a. Overhang of the mandible
   b. Mobility of the laryngeal framework
   c. Joints between the cartilages which tend to dislocate, thus avoiding fracture
   d. Common injuries are blunt injuries
   e. All of the above

5. Laser management is undertaken for
   a. Managing sequelae such as granulomas and scarring
   b. Vaporising prolapsed obstructing mucosa
   c. Vaporising prolapsed cartilage to restore the airway
   d. Arytenoidectomy for bilateral recurrent laryngeal nerve injury
   e. All of the above

6. The commonest iatrogenic trauma is
   a. Damage to the recurrent laryngeal nerve during thyroid surgery
   b. Due to long term intubation
   c. During intubation
   d. During crash intubation
   e. During endolaryngeal laser surgery

7. The most frequent iatrogenic damage due to laser surgery occurs in cases
   a. When removing papilloma from anterior commissure, both folds are denuded, resulting in web formation
   b. Ignition and fire of the anaesthetic tube or cuff
   c. When excising large bulky malignant tumour
   d. When laser is used repeatedly for excising fibrotic stenosis
   e. Where aggressive laser usage is undertaken to remove frequently recurring papillomas

Chapter 15

Bilateral vocal fold immobility

M. Remacle and G. Sandhu

Part A: An Overview

1. Terminology

Bilateral vocal fold palsy (BVFP) or bilateral vocal fold immobility (BVFI) are synonymous, both terms are commonly used to describe the lack of movement of both vocal folds. The terms do not, however, include cases where there is reduced mobility rather than immobility. The term bilateral vocal cord mobility impairment (BVCMI) is more accurate and preferred as it includes cases were there may be partial recovery or some degree of motion in at least one of the vocal folds.

2. Aetiology

In most cases, the impairment in the movement of the vocal cords on both sides can be due to:

- Bilateral denervation (thyroid surgery or neck and chest malignancy);
- Cricoarytenoid joint fixation (rheumatoid arthritis or trauma);
- Inter-arytenoid scarring (post intubation).

3. Symptoms

Irrespective of the aetiology, the symptoms are common in all cases. They consist of shortness of breath and variable degree of dysphonia. When the aetiology is bilateral recurrent laryngeal nerve damage, such as following thyroid surgery, the symptoms appear immediately in the postoperative recovery room. When they are due to external trauma, other injuries may take priority in management until a safe airway is established. Endolaryngeal injury may therefore present at a later date, particularly if it occurs as healing progresses with scar formation. Symptoms from arytenoid dislocation due to intubation trauma are immediate, where as those due to interaryntenoid scarring may develop some weeks after the event.

In mild cases, the symptoms of breathlessness are apparent only on exertion, whereas in severe cases there is a distinct inspiratory stridor which may require emergency airway management.

4. Grading of bilateral vocal fold mobility impairment

Grading of the severity of bilateral vocal fold immobility and the extent of joint fixation is useful to compare outcomes from different centres (Fig. 1).

Part B: Bilateral recurrent laryngeal nerve injury

Following *bilateral* recurrent laryngeal nerve injury, the vocal folds lose abduction and come to rest in a paramedian position. The patient experiences a significant shortness of breath and stridor. Severe shortness of breath requires emergency establishment of a safe airway which may be achieved through orotra-

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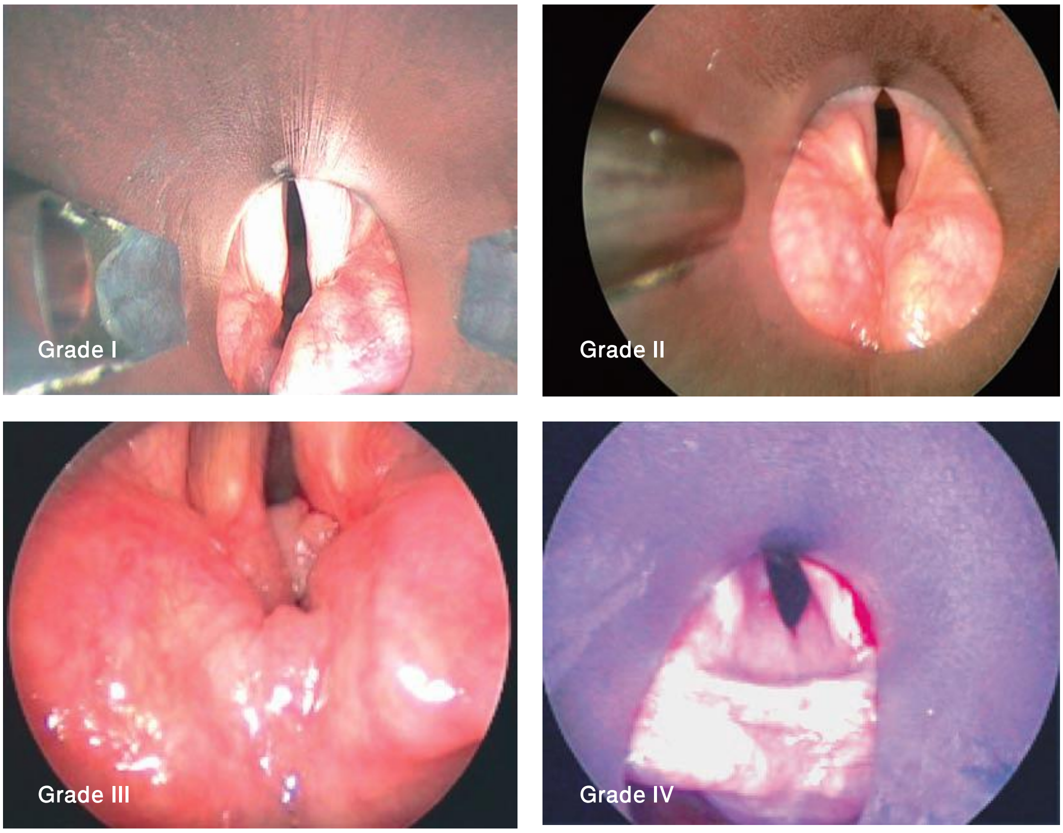

Fig. 1. Grading of bilateral vocal fold mobility impairment (cricoarytenoid joints are CAJs). Grade I – CAJs mobile/no scar. (Bilateral neurological deficit.); Grade II – CAJs fixed/no scar. (Bilateral joint damage from trauma or in this case arthritis.); Grade III – Early granular/inflammatory injury between the arytenoids. (Endotracheal tube trauma); Grade IV – Mature scar between arytenoids (may be thick or thin, due to maturation of grade-III injury).

cheal intubation followed by a tracheostomy. Early surgical, irreversible airway procedures should be avoided since, in cases of neuropraxia, there may be a possibility of return of glottis function through recovery of the recurrent laryngeal nerves.

Various techniques have been described for elective long term management.

5. Reinnervation

Various reinnervation techniques have been described. These include anastomosis of ansa cervicalis to recurrent laryngeal nerve or to thyroarytenoid neuromuscular pedicle. Some workers have undertaken anastomosis of hypoglossal nerve to recurrent laryngeal nerve. Various muscle nerve pedicle procedures have also been advocated. Most of these techniques lead to synkinesis and work best with unilateral cord palsies in restoring voice (Aynehchi *et al.*, 2010). More promising but as yet unpublished techniques, pioneered by Prof. Jean-Paul Marie in France, involves mobilising one division of the phrenic nerve or accessory phrenic nerve and anastomosing it to the posterior cricoarytenoid muscle. This manages to produce abduction on inspiration in the more successful cases.

6. Implantable electrical stimulation devices

Other groups have looked at reanimation of the paralysed human larynx with an Itrel II stimulator (medtronic, Inc) (Zealear *et al.*, 2003). These techniques are, however, in very early stage clinical trials.

Endoscopic surgical management is the method of choice in adults (Kleinsasser and Nolte, 1981). This approach is also efficient in children (Aubry *et al.*, 2010a; Aubry *et al.*, 2010b; Friedman *et al.*, 2001). However, in some children, a laryngofissure approach may be considered because of the limited access due to the small structures (Bower *et al.*, 1994).

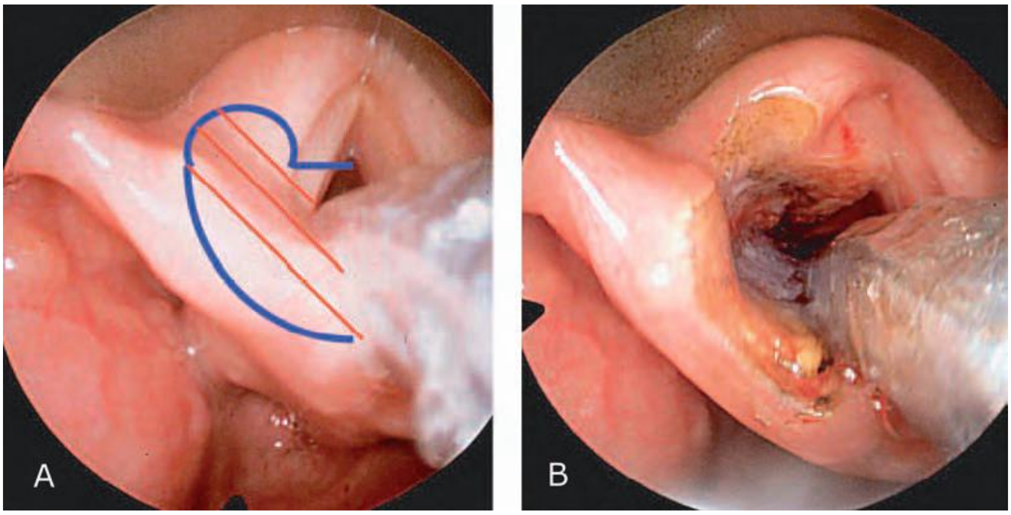

Fig. 2. A, B. Left subtotal arytenoidectomy.

7. Transoral laser surgery

Transoral laser excision of the arytenoid and/or posterior part of the vocal ligament is currently the method of choice. Although these patients are able to adduct the cord normally, and therefore have a good strong voice before the laser surgery, removal of part of the arytenoid results in a very breathy voice. The more adequate the airway, the worse is the quality of voice. The detailed management is described later in this chapter.

7.1. CO_2 laser-assisted total arytenoidectomy

Ossoff *et al.* (1983) in the USA and Frèche (Cabanes *et al.*, 1995) in France introduced CO_2 laser-assisted endoscopic arytenoidectomy for treating compromised airways.

The author (MR) uses a laser-adapted tube for ventilation in preference to jet ventilation. The tube affords protection to the posterior commissure from thermal damage, a factor crucial for a successful surgical outcome, since damage here would result in synechiae with recurrence of symptoms of compromised airway. The distal end of the laryngoscope is directed towards the arytenoid, away from the lumen of the laryngeal inlet. With the CO_2 laser scanning technology (Acublade®) in super-pulse or ultrapulse pulsed mode, a two to three mm long incision line is set to operate in a continuous mode, giving a power of 10-12 W (Remacle *et al.*, 2005a). Attachment of the vocal fold to the tip of the vocal process is severed by vaporising the tissue. It is important to continue the incision laterally through to the elastic cone in order to detach the vocal fold completely. The beam is then oriented towards the posterior end of the ventricular fold in order to enable dissection lateral to the arytenoids (Fig. 2).

Using a microforceps or suction cannula, the arytenoid is pushed forward. This stretches the soft tissue for efficient vaporisation and facilitates dislocation of the crico-arytenoid joint. Care must be taken to preserve the integrity of the posterior commissure. Frequent palpation with the tip of the suction ensures that the entire body has been removed. The bed is then covered with fibrin glue to prevent the formation of granuloma. Intraoperative bleeding from the arytenoid artery or from one of its branches is extremely frequent and is easily controlled with monopolar diathermy used with a suction coagulator (Remacle *et al.*, 1996b).

Although total arytenoidectomy is effective in restoring the airway adequately, it may at times result in significant aspiration. Excessive remnants of arytenoid mucosa may also prolapse into the airway, particularly during strenuous physical work and encroach up on the airway. A variety of modifications have been proposed to overcome these issues; they are described below.

7.2. Subtotal arytenoidectomy

A degree of rigidity can be provided to the new airway by leaving a one- or two-mm layer of the posterior surface of the arytenoid cartilage, thus forming a posterior, relatively rigid shell (Fig. 3). This is achieved by cutting through into the body of the arytenoid cartilage during the third stage of

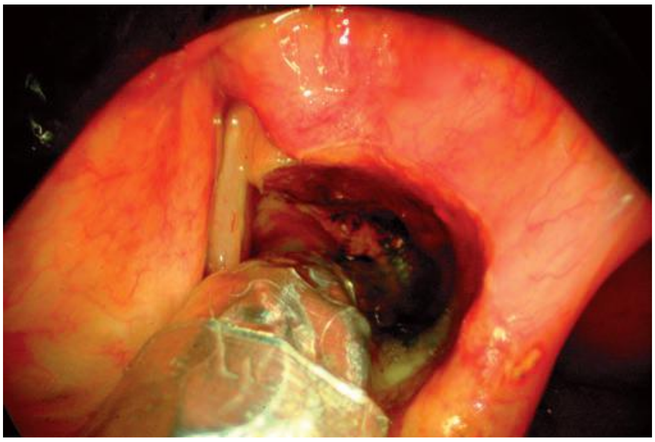

Fig. 3. Subtotal arytenoidectomy. Right vocal fold. The section of the vocal ligament extended to the conus elasticus allows a good anterior relaxation of the vocal fold. The posterior part of the arytenoids is clearly visible.

the operation. This cartilaginous shell also reduces the risk of aspiration. If the posterior shell appears to be too thick, it may be reduced by vaporisation with a CO_2 scanner (Plouin-Gaudon *et al.*, 2005).

7.3. *A very posterior minimal arytenoidectomy*

Minimal removal of arytenoids is advocated in order to ensure that the vocal integrity of the posterior larynx is not excessively compromised. This is particularly useful should spontaneous recovery occur, as good voice and glottic closure is then assured. It is of course necessary to carry out optimum cartilage excision on both sides in order to achieve an adequate airway. Crumley (1993) proposes removal of the arytenoid bodies alone whilst preserving the vocal process, together with the lateral and posterior walls of the body of the cartilage (Wani *et al.*, 1996).

The partial arytenoidectomy (Fig. 4a,b) is performed very posteriorly into the body of the arytenoid cartilage, on the one side initially, and repeated in the opposite arytenoid if necessary. All patients need to be pre-assessed for baseline swallowing function. This technique has been successful in decannulating all patients with bilateral recurrent laryngeal nerve palsies and improving respiratory function in the others. This very posterior technique has the advantage that the whole vocal fold does not become lateralised as in techniques where the vocal process of the arytenoid is lasered or where a suture lateralisation is employed.

7.4. *Arytenoidectomy with preservation of the arytenoid mucosa*

In order to avoid posterior synechiae or granuloma, Lichtenberger and Toohill (Lichtenberger and Toohill, 1997) recommend tailoring a posterior mucosal flap before arytenoidectomy. The remaining vocal fold is fixed laterally with through-stitches in the posterior and middle third, with the help of the endo-extralaryngeal needle carrier (Fig. 5).

The skin incision is taken in the same line as the previous incision for thyroidectomy. The flap of skin and platysma is raised. One end of the lateral fixation suture is pushed through the larynx *below* the posterior third of the vocal cord. The other end is passed *above* the posterior third of the vocal cord.

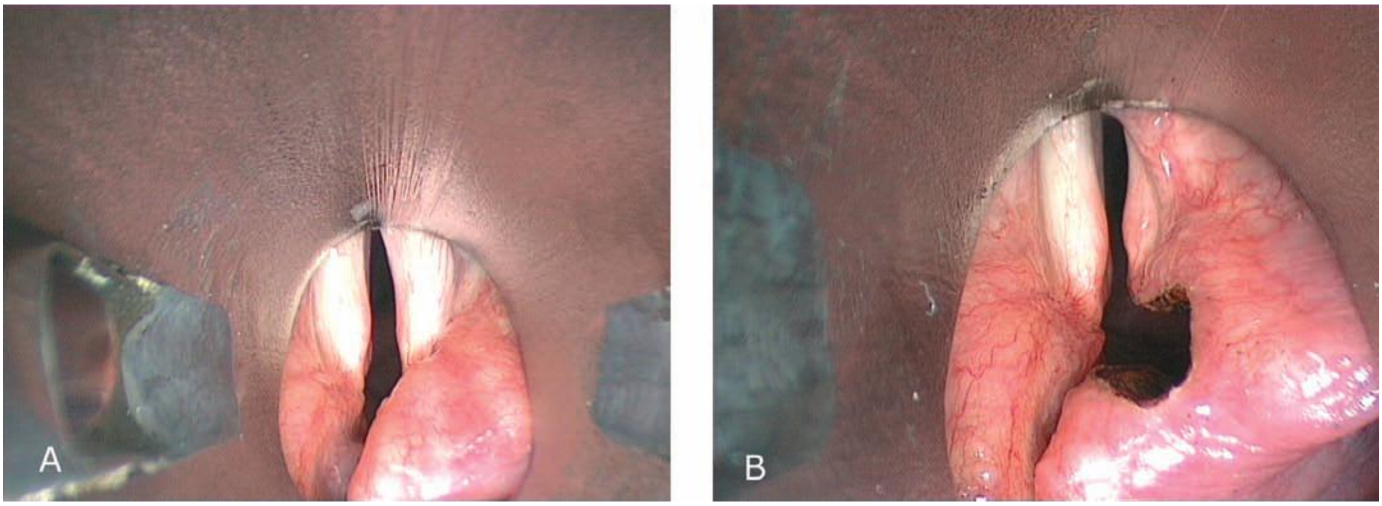

Fig. 4. A, B. Showing right laser arytenoidectomy procedure for grade I BVCMI. The procedure is repeated on the other side, if the airway prooves inadequate for patients' needs (Photo: G. Sandhu).

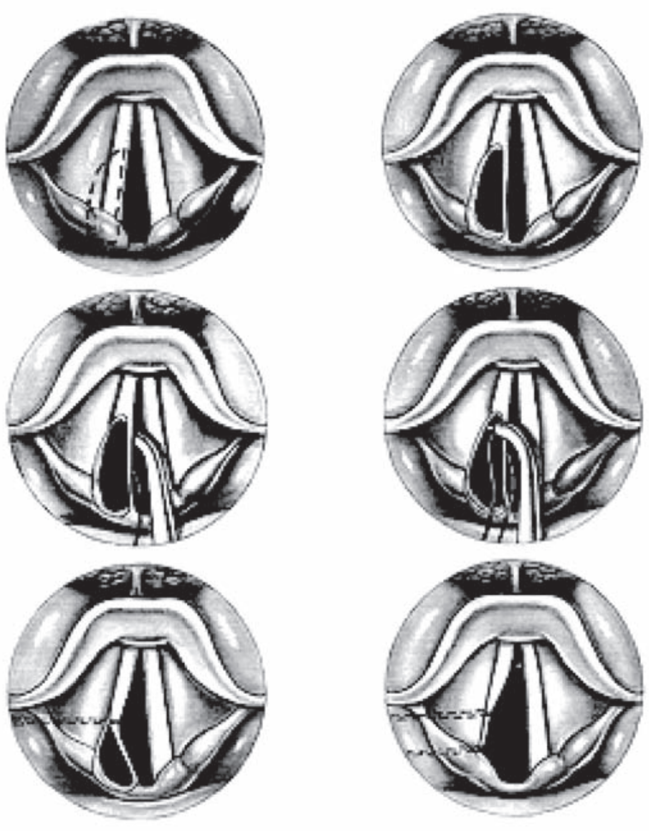

Fig. 5. Permanent laterofixation of the vocal fold.

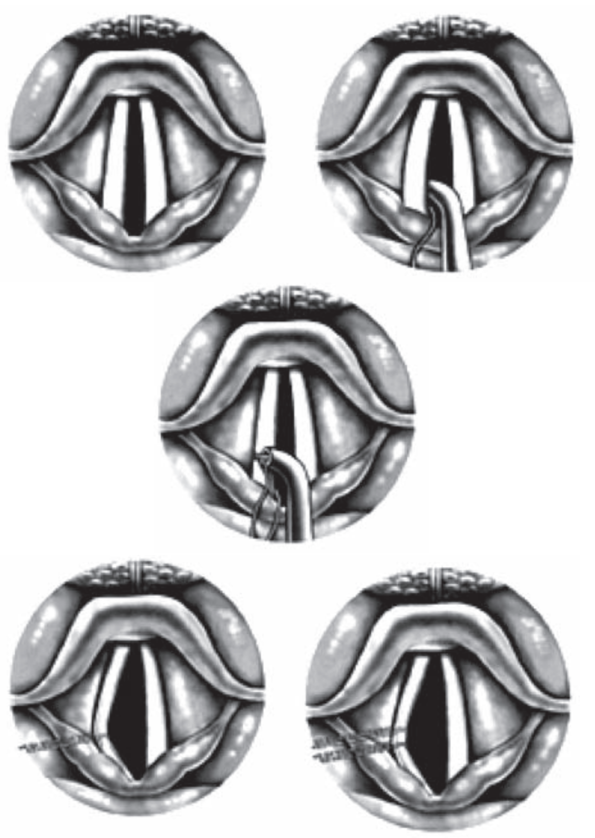

Fig. 6. Temporary lateral fixation of the vocal fold.

The ends of the fixation suture are pulled and knotted over a small silicone sheet placed on the thyroid cartilage or on the sternohyoid muscles. Fixation suture is removed two to three weeks postoperatively.

Temporary lateral fixation of the vocal cord is the only potentially reversible procedure for glottic airway enlargement (Fig. 6).

It is indicated if the vocal cords are in paramedian position, functional recovery of at least one vocal cord is anticipated, and there is no scar formation in the lumen of the larynx. Once recurrent nerve function has recovered, the endoscopically performed lateral fixation of the vocal cord can be reversed.

7.5. Laser-assisted posterior cordectomy

Dennis and Kashima (1989) proposed uni- or bilateral posterior cordectomy. This technique claims to preserve voice quality but can be insufficient in one session (Lawson *et al.*, 1996). Extended posterior cordectomy has therefore been proposed by various workers. Pia and colleagues (1999) proposed to extend the resection to the ventricle. Reker and Rudert (1998) further refined the procedure by performing a transverse cordotomy, extending the resection to the muscle of the anterior two-third of the vocal fold. Combination of posterior cordectomy and arytenoidectomy has also been reported (Bizakis *et al.*, 2004).

7.6. Tenotomy

Rontal and Rontal (1994) suggest cutting the ligamentous insertions of the interarytenoid and thyroarytenoid muscles. The muscles thus retract away from the midline and the glottis is enlarged. The extent of the excision of the arytenoid cartilage is much less following tenotomy, thus avoiding postoperative aspiration and preventing secondary ankylosis of the crico-arytenoid joint. Therefore, this technique improves voice preservation. The procedure can be performed either via an endoscopic or an external approach with an operating microscope. However this technique, although very interesting from the conceptual point of view, does not seem to be reproducible.

8. Comparison: cordectomy versus arytenoidectomy

To date, no significant difference has been reported between posterior cordectomy and arytenoidectomy with regard to a vocal or respiratory outcome (Eckel and Vossing, 1996; Lawson *et al.*, 1996). Cordectomy is quicker and easier to perform and is more effective in the short term. The technique is frequently performed on both vocal folds. Revision surgery is often necessary, due to fibrosis which contracts at the site of the incision. Although arytenoidectomy is a lengthier and more laborious procedure, it results in a more sustained and stable outcome.

Irrespective of the technique employed, the postoperative follow up is usually uneventful. In tracheostomised patients, decannulation takes place as soon as the operative site has healed. Under the supervision of a voice therapist, deglutition is resumed as early as the following morning. Swallowing fluids can be troublesome after total arytenoidectomy.

An improvement in the airway inevitably results in poor voice quality. The aim of surgery should be to provide an adequate airway, which allows the patient to undertake daily routine activities without breathlessness (walking, swimming, or climbing a flight of stairs). The improved airway may not be adequate for a more strenuous activity (*e.g.*, playing tennis). However, this degree of airway competency results in a quality of voice that is adequate for one-to-one and telephone conversations. Nevertheless, the voice lacks loudness, essential for conversing in noisy surroundings.

Part C: Bilateral arytenoid cartilage fixation

Bilateral arytenoid cartilage fixation closely resembles vocal fold immobility resulting from recurrent laryngeal nerve paralysis. According to Eckel *et al.* (2003), stenosis due to recurrent laryngeal nerve paralysis could be managed endoscopically without preliminary tracheotomy, whereas bilateral arytenoid cartilage fixation requires temporary tracheostomy and open surgery.

9. Aetiology

The incidence of injury to cricoarytenoid joint is very small (House *et al.*, 2010) and described at approximately 0.1% of tracheal intubations. Injury to joint results in cricoarytenoid subluxation. The commonest cause is intubation trauma, particularly in difficult cases (short neck, overweight, TM ankylosis, cervical spondylitis, etc.) and during crash intubation. The tip of the laryngoscope can cause subluxation in these patients. Finally, blunt neck trauma can also result in subluxation.

In long-standing cases of joint subluxation, joint fixation occurs in subluxated position and the movement of the vocal fold is either severely impaired or non-existent.

Bilateral subluxation and fixation as a result of trauma is even more unusual (case reports only).

In the absence of history of trauma fixation also may be due to rheumatoid arthritis affecting the cricoarytenoid joints.

It is even more important to assess swallowing difficulties in these patients as connective tissue disorders often lead to problems with the cervical spine and consequently impact on swallowing.

10. Management

The management of bilateral fixed cricoarytenoid joints is similar to that of recurrent laryngeal nerve palsy in that a laser arytenoidectomy is performed unilaterally or bilaterally depending on the sever-

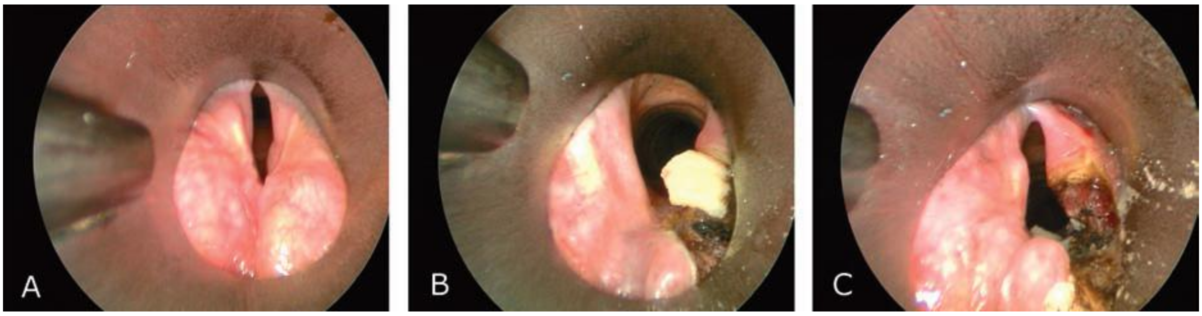

Fig. 7. Grade II BVCMI, right laser arytenoidectomy performed, degenerative material from cricoarytenoid joint (centre).

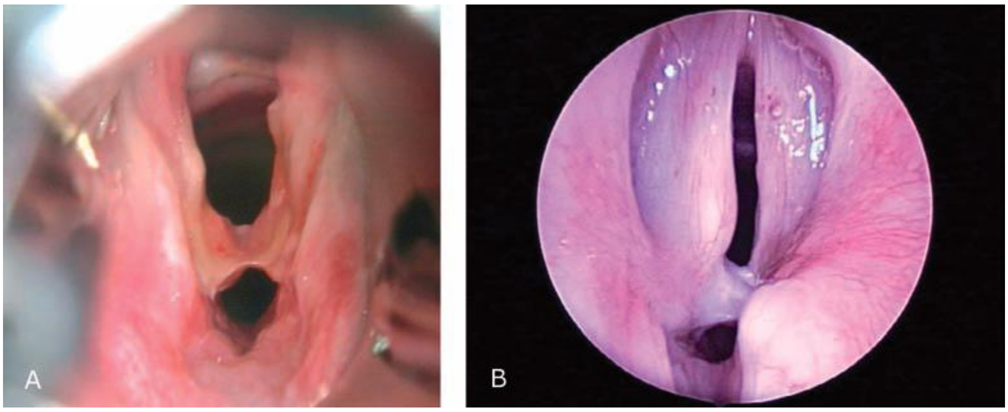

Fig. 8. A. shows vocal fold granulation tissue formed as a result of endotracheal intubation coalescing. If undivided this will become mature scar tissue (B) and eventually leads to ankylosis of cricoarytenoid joints.

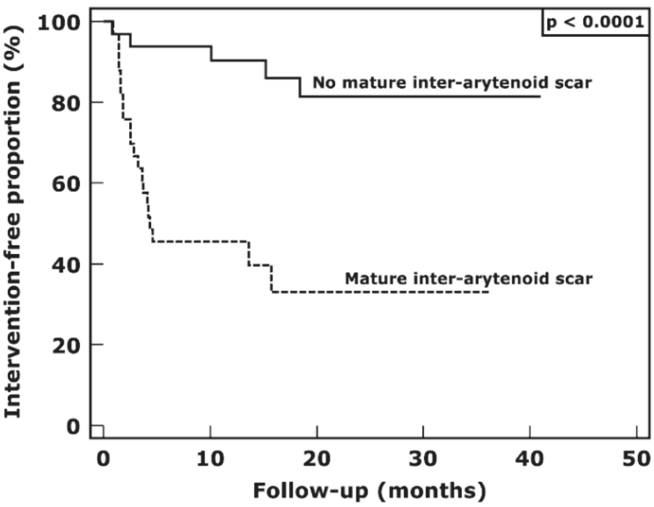

Fig. 9. Difference in the treatment of mature interarytenoid scar versus non-mature scar (granulation).

ity of the symptoms. Figure 7 demonstrates a laser arytenoidectomy in a patient with fixation of the cricoarytenoid joints due to rheumatoid arthritis. The centre picture shows degenerative material exuding out of the cricoarytenoid joint during the laser procedure.

Part D: Interarytenoid scarring

Long-term intubation in some cases leads to inter-arytenoid scarring. Vocal process granulomas coalesce to form adhesions between the arytenoids, this leaves the inter-arytenoid mucosa of the posterior commissure unaffected (Fig. 8A,B).

In the case of Figure 8A, the immature adhesion can simply be severed and normal vocal fold function will resume. If this granular injury is allowed to mature such as in Figure 8B, then there will be ankylosis of the cricoarytenoid joint and even division and balloon dilatation will not restore vocal fold mobility. A compromise between voice and airway is inevitable.

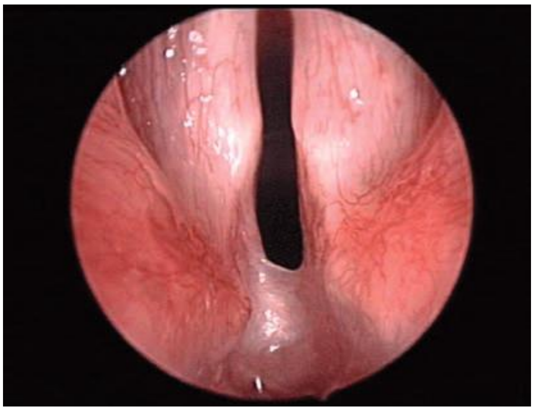

Fig. 10. Thin interarytenoid scar.

Therefore, in the cases of inter-arytenoid scarring, distinction must be made between early granular inflammatory injury (grade III) (Fig. 8A) and mature scar tissue between the arytenoids (grade IV) (Fig. 8B).

11. Management

Management of grade-I and grade-II injuries has already been described. Grade-III injuries present early and usually demonstrate a granular inflammatory response between the arytenoids (Fig. 9). This must be treated with steroid injection, gentle reduction of granulation tissue, topical application of mitomycin-C and balloon expansion of the posterior

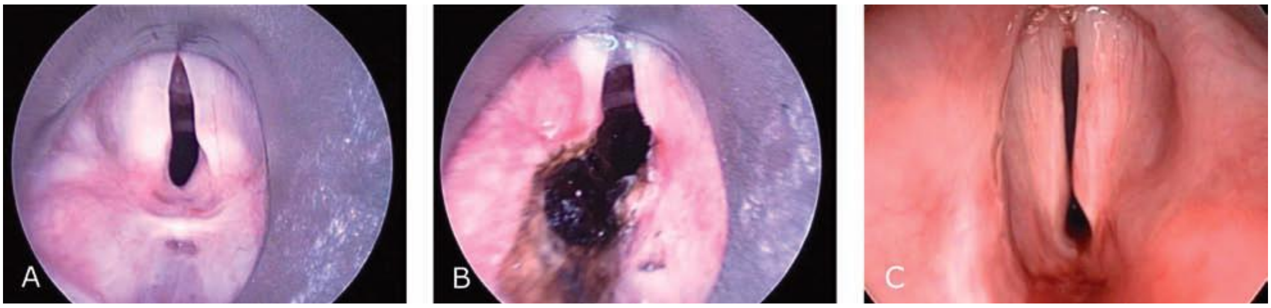

Fig 11. A. Thick interarytenoid scar; B. Extended laser arytenoidectomy and scar division; C. Quickly reforming scar tissue..

glottis at two to three weekly intervals to prevent mature scar formation between the arytenoids.

It is evident that grade-III injuries are the type least frequently seen. Figure 10 shows an example of thin inter-arytenoid web which is amenable to division with a sickle knife, balloon dilatation and topical mitomycin-C application. This procedure, if repeated at three to four weekly intervals, may result in complete resolution.

Unfortunately, the majority of the interarytenoid scar cases are mature at presentation, thicker and more fibrotic, as demonstrated in Figure 11A. A large laser arytenoidectomy shows an excellent airway intraoperatively (Fig. 11B), however, the healing process shows reformation of the scar and narrowing of the posterior glottis in a few weeks (Fig. 11C).

In the cases of dense interaytenoid scar tissue, the immediate post-operative results of laser reduction of this tissue may be very good, however, the scar duly reforms. In some cases, it is even more extensive than preoperatively.

One author (GS) has tackled this problem by laryngo-fissure and posterior cricoid split. The scar is divided and a piece of costal cartilage is interposed (Chapter 16, Fig. 17). The cartilage acts as a temporary spacing device. In a large number of cases, this piece of cartilage is resorbed. However its role is not augmentation but separation of the scar for healing to take place without contracture. This technique is also helpful in cases where the posterior injury and damage extends to the subglottis.

12. Conclusion

Currently, all efforts must be made at prevention and it is therefore recommended that intensive care units consider early tracheostomy in patients who are potentially going to be ventilated for more than one week. Early intervention with steroids and mitomycin-C in grade III lesions also needs to be promoted. The future management of grade-1 lesions probably lies in laryngeal pacing or novel reinnervation techniques. The management of grade-II and -IV lesions will be, for the time being, an inevitable compromise between voice and airway.

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MCQ – 15. Bilateral vocal fold immobility

1. Impaired mobility of the bilateral vocal folds is more accurately described by
    a. Bilateral vocal fold palsy (BVFP)
    b. Bilateral vocal fold immobility (BVFI)
    c. Bilateral vocal cord mobility impairment (BVCMI)
    d. Bilateral Vocal fold paralysis
    e. All of the above

2. The commonest cause for bilateral vocal fold immobility is
    a. Cricoarytenoid joint fixation
    b. Inter-arytenoid scarring
    c. Bilateral denervation
    d. Malignant infiltration of both vocal fold
    e. Anterior commissure infiltration with malignancy

3. The most commonly used method to restore the airway is
    a. Re-innervation
    b. Muscle nerve pedicle procedures
    c. Implantable electrical stimulation devices
    d. Endoscopic surgical management
    e. Tracheostomy

4. Possible risk factors associated with total arytenoidectomy are
    a. Perichondritis
    b. Granuloma
    c. Aspiration
    d. Dysphonia
    e. Webbing

5. In order to maximise adequate postoperative voice, modifications have been described
    a. Subtotal arytenoidectomy
    b. Lateralisation of vocal fold instead of arytenoidectomy
    c. A very posterior minimal arytenoidectomy
    d. Laser-assisted posterior cordectomy
    e. All of the above

6. Incidence of synechiae is minimised by
    a. Undertaking submucosal arytenoidectomy
    b. Using mytomycin C
    c. Covering raw surface with fibrin glue
    d. Laser-assisted posterior cordectomy
    e. All of the above

7. Advantages of total arytenoidectomy are:
    a. A sustained improvement in airway
    b. Preservation of useful voice
    c. A long term unimpaired swallowing
    d. Reversibility
    e. Repeatability

8. Disadvantages of total arytenoidectomy are
   a. Stridor on exertion
   b. Episodes of aspiration
   c. Inadequate airway
   d. Granuloma
   e. All of the above

9. Comparison: cordectomy versus arytenoidectomy
   a. Cordectomy results in marked dysphonia
   b. Arytenoidectomy provides adequate airway
   c. Unilateral cordectomy may not provide adequate airway
   d. Posterior cordectomy and partial arytenoidectomy is advocated to provide both adequate airway and phonatory result
   e. Cordectomy may result in aspiration in early postoperative period

10. Bilateral arytenoid cartilage fixation
    a. Mimics immobility due to denervation
    b. Reinnervation is the method of choice to achieve improvement in airway
    c. Steroid injections in the affected joints is the first line of treatment
    d. Transoral laser management is usually ineffective
    e. Presenting symptom is aphonia

11. Interarytenoid scarring
    a. Results from maturation of bilateral granular tissue affecting arytenoid cartilages
    b. Simple division of the scar usually restores mobility
    c. Early cases are treated with division, balloon dilatation, Mitomycin-C, steroid injections and gradual reduction of granulations.
    d. Division of scar and interarytenoid splint is required in mature cases to prevent restenosis.

12. Tracheostomy for bilateral abductor palsy
    a. Results in immediate restoration of airway
    b. Phonation is unaffected
    c. Swallowing is unaffected
    d. Is associated with low morbidity
    e. Does not require specialised equipment or training

Chapter 16

Endoscopic laser management of the compromised laryngotracheal airway

G.S. Sandhu and S.A.R. Nouraei

Part A: Laryngotracheal stenosis (LTS)

1. Introduction

Before the twentieth century, the principle cause of laryngotracheal stenosis (LTS) was from infections such as tuberculosis, syphilis and diphtheria. The first elective surgical procedure performed using *orotracheal intubation* was by an Edinburgh surgeon, William MacEwen, in 1878 to remove an oral tumour. During the polio epidemic in Copenhagen in 1953, Bjorn Ibsen was the first to set up an Intensive Care Unit. These developments and the successful treatment of many infections have made endotracheal intubation the most common cause of laryngotracheal injury. In the author's experience, over 50% of adult LTS is from periods of ventilation in the Intensive care unit (Fig. 1A, B). Due to medical advances, more patients are surviving periods of ventilation in intensive care units (Williams *et al*., 2005, www.icnarc.org). As a consequence, the incidence of laryngotracheal injury is probably increasing, but precise data are lacking.

Ninety-five percent of paediatric LTS is acquired and is most commonly from prolonged intubation.

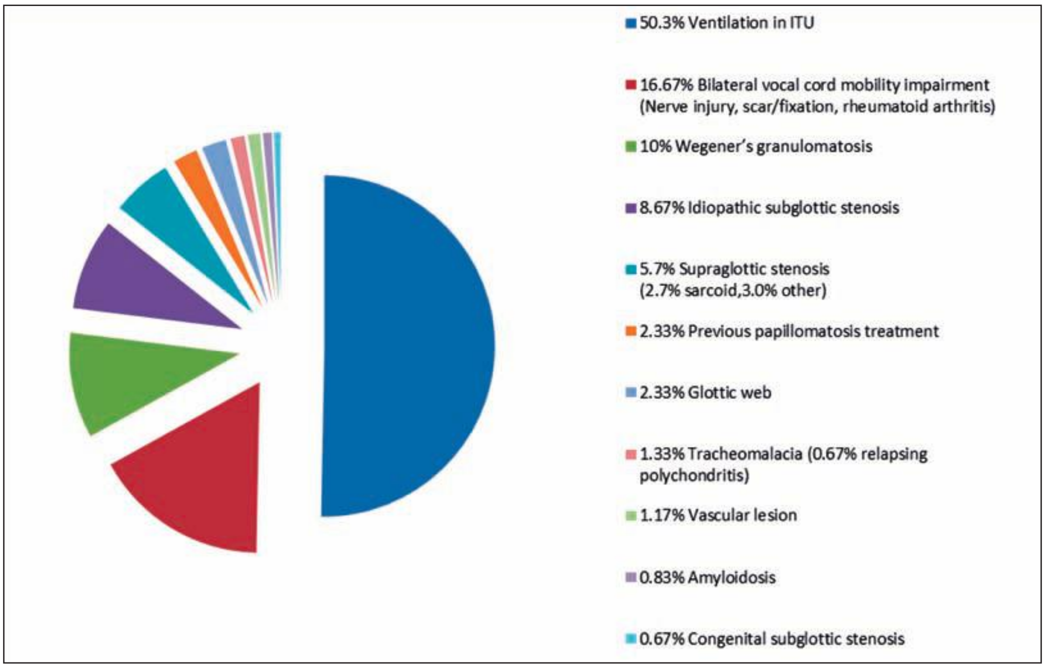

Fig. 1a. Analysis of site-specific aetiology of 600 consecutive cases referred to Airway Reconstruction units.

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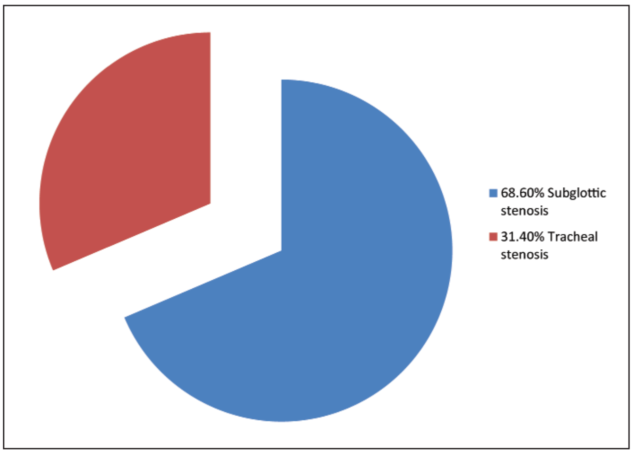


Fig. 1b. Site-specific acquired laryngotracheal stenosis, secondary to ventilation in intensive care units: most common sites.

2. Effects of narrowing of laryngo-tracheal complex

Abnormal narrowing of the laryngotracheal complex causes breathlessness, especially during physical activity. Retention of pulmonary secretions may lead to lung infection or collapse. Laryngeal stenosis can interfere with phonation and a dysfunctional larynx can affect swallowing safety. The exact physiological causes of dyspnoea are not known, however, the extra work of breathing, altered afferent input from the respiratory tract and the tendency towards carbon dioxide retention may play a part.

3. Paediatric LTS

Paediatric LTS is a well-researched area of compromised laryngotracheal airway. It nearly always involves the subglottis (Cotton, 1991) and prolonged endotracheal intubation is by far the most common aetiology. Treatment strategies include airway augmentation with rib grafts as well as tracheal and cricotracheal resections. The lesional anatomy, anatomical sites and pathologies of paediatric laryngotracheal stenosis differ greatly from the adult group. Paediatric laryngotracheal compromise is discussed in Chapter 18 in detail.

4. Adult LTS

Adult LTS has been poorly researched and the surgical options include tracheostomy, tracheal resection or cricotracheal resection (Grillo *et al.*, 1995). Some surgeons still use primary cartilage grafts to augment the adult airway. There has been little appreciation of the fact that there is a high incidence of ischaemic necrosis of primary rib graft in adult patients (Schultz-Coulon *et al.*, 2011). Furthermore, the quality and quantity of rib cartilage that can be harvested diminishes with age (Schultz-Coulon *et al.*, 2011).

5. Post-intubation LTS: Literature review

The birth of the first ICU in 1953 led to an ever widening use of mechanical ventilation to treat respiratory failure. The iatrogenic lesions that resulted provided a whole new field of endeavour for surgeons. In the 1960s, scores of papers appeared in Europe and North America, describing surgical resection of post intubation strictures. Prevention of post intubation injury quickly became a priority once the origin of these lesions was evident. Initially high pressure cuffs were used and risked ischaemic injury to the mucosa and necrosis of the cartilage of the trachea. Carroll and colleagues (1969) recommended a cuff with a large volume and low pressure which only resulted in small increases in tracheal wall pressure with over-inflation. Although the incidence of post intensive care unit airway stenosis is unknown and can only be approximated at between 1-4% (Arbuckle, 1927; Healy, 1989; Lund *et al.*, 1985; Lorenze, 2003), a significant early injury is evident in 47% of patients (Esteller-More *et al.*, 2005). This is despite the use of the high volume, low pressure cuffs on endotracheal and tracheostomy tubes.

The anatomical and pathological differences between stomal and cuff stenoses and other post intubation injuries were described at this time by Pearson (1968) and Grillo (1969). They stressed the importance of allowing florid inflammation to subside prior to surgical correction (Deverall, 1967; Grillo, 1969; Pearson *et al.*, 1968; Couraud *et al.*, 1969). They demonstrated that surgical resection and anastomosis produced better results than repeated dilatation, steroid injection or cryotherapy. The results of treating post-intubation stenosis with resection by the same colleagues achieved an 87.5% ‘cure’ in 200 patients in 1992. The definition of ‘cure’ appeared to include patients with a suboptimal airway. Couraud and colleagues reported a 96% success rate in 217 patients in 1994, and Grillo and colleagues cited a 94% success in 503 patients in 1995

(Grillo *et al*., 1995; Bisson *et al*., 1992, Couraud *et al*., 1994). They also described the correction of post intubation stenosis involving the subglottic area as being more difficult than lesions of the trachea.

6. Pathogenesis of LTS

The pathogenesis of post-intubation stenosis injuries was initially unclear. At first it was thought to be due to irritation from the materials from which tubes and cuffs were made (Cooper and Grill, 1969). Later it became clear that pressure necrosis from tubes and cuffs leading to circumferential injury and contracture was the principal explanation (Andrews and Pearson, 1971). However, whatever the mechanism for eventual formation of stenosis, there are certain risk factors which contribute to its formation. Avoidance of these factors to minimise the risk is perhaps the best management strategy!

7. Risk factors

There are a number of risk factors for LTS following a period of ventilation on the intensive care unit. These contributory risk factors for laryngo-tracheal stenosis are:

- Oversizing of endotracheal tubes;
- Duration of intubation;
- Patient movement and agitation;
- Excessive lateral cuff pressure unnoticed if cuff pressure monitoring is poor;
- Hypotension;
- Local infection;
- Immuno-compromised patients;
- Use of steroids;
- Extra-oesophageal reflux;
- Co-morbidity (*e.g*., diabetes mellitus and arteriopathy);
- Altered immunity as part of the stress response;
- Collapse of cartilage at the site of tracheostomy.

It has to be noted that although prolonged intubation in the ITU is one of the risk factors in the development of LTS, the majority of patients ventilated on ICUs do not appear to develop airway stenosis.

In addition to these risk factors, patients who tend to scar excessively following injury, may be more prone to airway stenosis, although there is no clinical study to support this.

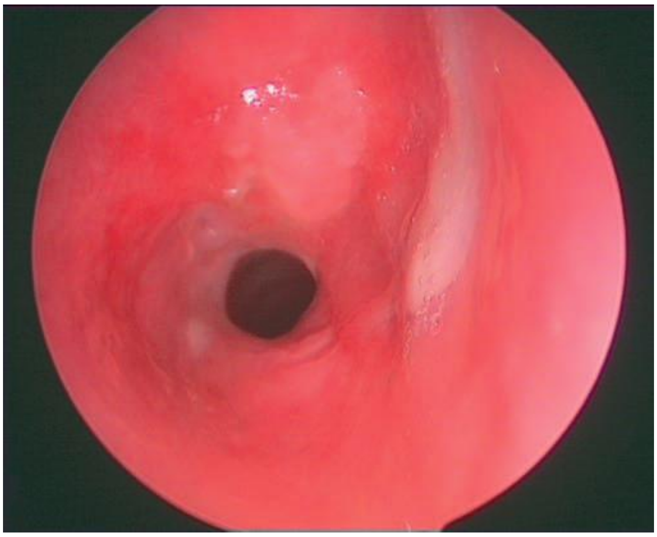


Fig. 2. Typical appearance of tracheal injury at extubation on the ICU.

Stenosis at the site of tracheostomy was described as early as 1886, when Colles found four strictures in 57 patients treated for diphtheria (Colles, 1886). Based on the authors' experience (Fig. 2), the incidence of airway stenosis from endotracheal tubes is approximately the same as the incidence of stenosis at the site of tracheostomy.

8. Laryngo-tracheal resection: Literature review

Prior to an endoscopic approach, LTS resection was undertaken via an external, transcervical approach. Rigveda, one of the oldest extant texts in any Indo-European language, composed in the north-western region of the Indian subcontinent roughly between 1700–1100 BC (Szmuk *et al*., 2007), noted that the trachea could re-unite 'when the cervical cartilages are cut across, provided they are not entirely severed'. This description dates from about 2000 BC. The earliest description of management for LTS was by L. Von Schroetter in Vienna in 1871, who described dilatation with rubber bougies passed through the mouth (Jackson, 1936; Winslow, 1909). Gluck and Zeller (1881) demonstrated adequate healing after end-to-end tracheal anastomosis in dogs and believed that the technique could be applied in man.

Primary anastomosis of the trachea after limited resection for post-traumatic stenosis was performed by Kuster (1886) in man. Nowakowski (1909) described a complex method of repair of cervical tracheal defects and, through cadaver studies, placed the limit of tracheal resection at three to four cm. It was many years later that Conley (1953) successfully resected the second and third tracheal rings with primary end-to-end anastomosis. In 1968, Grillo reported the length of trachea that could be resected for post-intubation stenosis at 4.5 cm (approximately 7.2 rings). He discovered that the length that could be resected in older patients was progressively shorter because of the reduced elasticity between the cartilaginous rings. He further demonstrated that it would be possible, with additional manoeuvres involving release of pulmonary ligaments and suprahyoid laryngeal release, to resect a further two cm (Mullikem and Grillo, 1968). Although many other techniques have been described, the next significant advance was in 1972 with Fearon and Cotton in Toronto, publishing an experimental procedure where thyroid cartilage was used to augment an anteriorly split thyroid cartilage in a monkey. They also demonstrated that there was no inhibition of laryngeal growth following this. In 1974, Evans and Todd in London reported the use of rib cartilage in laryngo-tracheoplasty, but favoured a castellated laryngofissure to expand the airway over a piece of rolled silastic sheet used as a stent for six weeks. Cotton in Cincinnati (1978) described in detail laryngo-tracheal reconstruction (LTR) with an anterior costal cartilage graft. Later, Cotton (1984) published a series of 100 cases of LTR in children over a decade. He emphasised that the stenosis should be mature before undertaking open surgery. In 1985, Fearon and McMillin in Toronto described cricoid resection and thyro-tracheal anastomosis in primates. They demonstrated that there was no interference with normal laryngeal growth following surgical intervention. Ranne and colleagues in Kansas City are credited with the first cricoid resection in patients, published in 1991. This procedure, originally described by Pearson and co-workers in 1975, was adopted by Monnier in Switzerland, who subsequently published his series in 1993. Robin Cotton's group in Cincinnati, when considering an open procedure for subglottic stenosis, primarily performed anterior and posterior augmentations.

There has been very little research directed at the endoscopic approach to laryngotracheal airway compromise and the long-term outcomes of this technique.

9. Assessment of the patient with airway compromise

A full medical history is essential. The duration of symptoms of shortness of breath and details of intubation, trauma and tracheostomy should be determined. Knowledge of co-existing medical conditions such as asthma, chronic obstructive airways disease and vasculitis is essential. Questions should also be directed at quality of voice and swallowing and investigations such as video swallow studies should be requested if there are any doubts about the integrity of swallowing.

After documenting the degree of stridor, chest recession and quality of voice, a thorough examination of the neck and upper aerodigestive tract should be performed. Trans-nasal flexible laryngoscopy will allow assessment of vocal cord mobility, may demonstrate the stenosis, and provide evidence of swallowing problems and extra-oesophageal reflux. Where there is a tracheostomy, the flexible laryngoscope should be passed to assess the trachea and if possible the glottis from below. Patients should also be referred for assessment of respiratory function which should include spirometry and flow-volume loops (Sandhu and Howard, 2006). The pattern of flow volume loops are frequently diagnostic of the nature and site of the airway stenosis (Fig. 3). It is also important to determine the patient's body mass index (BMI) as this is highly prognostic in the success of airway surgery (Nouraei *et al.*, 2007). The author frequently refers patients for dietetic advice or bariatric surgery prior to definitive airway procedures.

9.1. Objective sizing of LTS

Objective sizing of LTS can be performed using computed tomography (CT), especially high-resolution imaging with multi-planar reconstruction (Fig. 4, right). It provides the best *anatomical* information (Brown *et al.*, 1991). CT scans cannot, however, differentiate between the true lumen and overlying secretions and crusting which introduces inaccuracies (Dorfell *et al.*, 1999). Furthermore, a CT scan works on the principle of cross-sectional sampling of anatomy and since the calibre of the airway is not orientated perpendicular to the plane of the scan, the combination of slice thickness and image reconstruction can introduce further inaccuracies. High-definition CT scans which largely overcome these problems are expensive and introduce a high

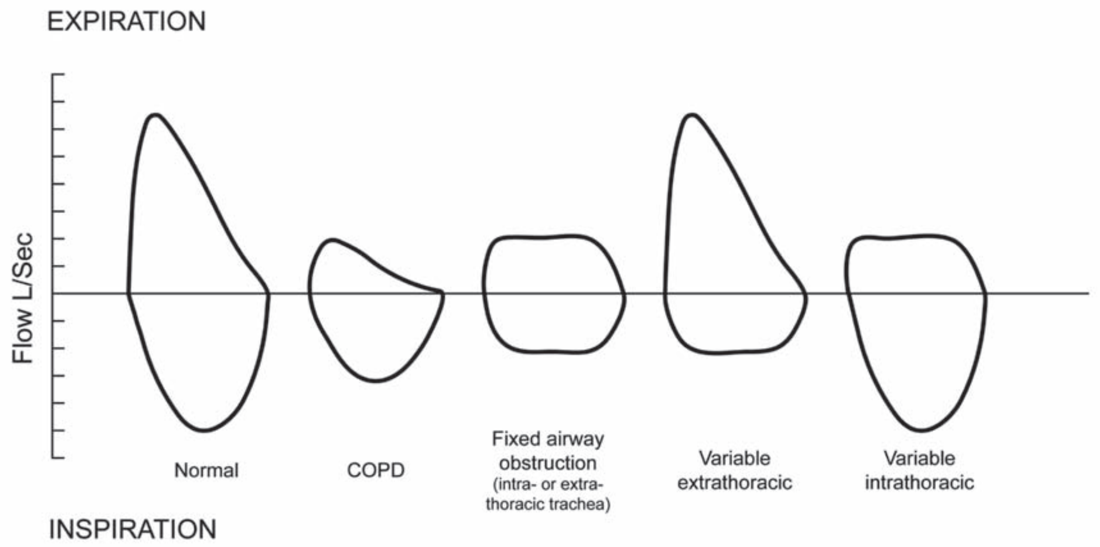
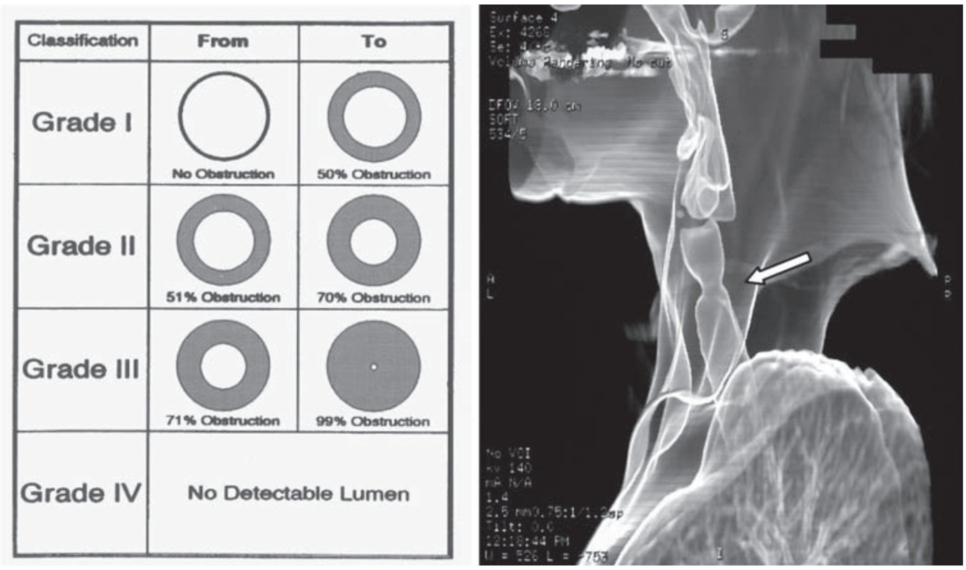


Fig. 3. Patterns of flow volume loops – these graphically depict the rate of airflow on the Y-axis and the total volume expired (above) inspired (below) on the X-axis. The patient is asked to take the deepest breath, apply the mouth to the device, and breathe out as hard as possible and for as long as possible. This is followed by a maximum and rapid inspiration (Sandhu and Howard, 2006). (COPD: chronic obstructive pulmonary disease.)



Classification	From	To
Grade I	No Obstruction	50% Obstruction
Grade II	51% Obstruction	70% Obstruction
Grade III	71% Obstruction	99% Obstruction
Grade IV	No Detectable Lumen	

Fig. 4. The Myer-Cotton Grading System (left) for paediatric laryngotracheal stenosis (Myer *et al*., 1994). CT scan with image reconstruction to show subglottic stenosis (right).

dose of radiation, making them unsuitable for monitoring patients through what can be a multi-stage treatment process.

Pulmonary function testing (Czaja and McCaffrey, 1996) does provide an indication of the severity of airway stenosis, but does not provide accurate anatomical information. Other methods proposed for airway sizing have included acoustic reflection techniques (Czaja and McCaffrey, 1996).

Endoscopy is the main tool for assessing and treating LTS. It allows direct visualisation of luminal pathology, observation of laryngotracheal dynamics and institution of endolumenal therapy (Dorffel *et al*., 1999; Doolin and Strande, 1995; Forkett *et al*., 1996). Robin Cotton of Cincinnati Hospital, Ohio, originally devised a grading system of airway stenosis in paediatric patients, based on leaks around different sized endotracheal tubes at ventilating pres-

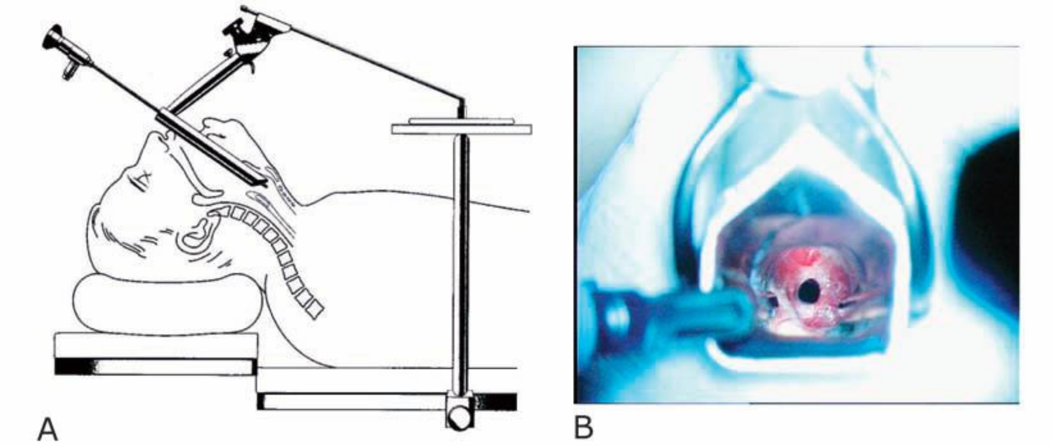


Fig. 5. A. Ideal patient position for suspension microlaryngoscopy based on work by Chevalier Jackson (1915); B. View of the stenosis via the microscope, with the laser spot visible.

sures of just beyond 30 cm of water. The system was revised into the Myer-Cotton grading system. This classifies subglottic stenosis into four grades (Fig. 4, left).

10. Anaesthesia for surgery on the airway

Suspension laryngoscopy is performed routinely by otolaryngologists for access to the supraglottic and glottic larynx (Fig. 5). *Laryngologists* are also comfortable operating on the subglottis via the microscope or rigid endoscopes. The advantages of the microscope are binocular vision, depth of field and superior axial illumination. It also allows both hands free for instrumentation. The laser can be used with a 'line-of-sight' technique through a micromanipulator attached to the microscope. Many laryngologists routinely use the ventilating bronchoscope for tracheal or bronchial assessment and surgery. Suspension laryngoscopy allows the use of both optical rigid endoscopes and flexible bronchoscopes to access the airway. The advantages are that the patient is paralysed and the full spectrum of rigid instrumentation, dilators, lasers and stents can be inserted and used with relative ease.

As the patient is ventilated using a supraglottic jetting technique, lasers can be used without the risk of airway fires. Low-frequency jet ventilation can be applied via hand-triggered devices such as the Sanders injector or Manujet and high frequency jet ventilation via a Mistral type device (Acutronic, Switzerland) (Fig. 6). Subglottic jet catheters and microlaryngoscopy endotracheal tubes can easily be inserted via the laryngoscope to support ventilation if required. Endoscopic airway assessment is performed by respiratory physicians, thoracic surgeons and otolaryngologists. Pulmonologists and thoracic surgeons are often skilled in the use of both flexible and rigid bronchoscopes. Flexible bronchoscopy is usually performed under topical anaesthesia in sedated, spontaneously breathing patients, applied to the upper aero-digestive tract. This technique allows assessment of the dynamic airway, the trachea and bronchi with the ability to perform the full spectrum of interventions. However, with a flexible bronchoscope placed through a narrow stenosis, the patient's airway becomes obstructed. Similarly, attempted dilatation of an airway stenosis leads to temporary airway obstruction. The rigid ventilating bronchoscope requires the patient to be paralysed and ventilated by a face mask or endotracheal tube until the bronchoscope is inserted. For assessment of the airway beyond an area of stenosis, the bronchoscope has to be forced through the stenosis. This

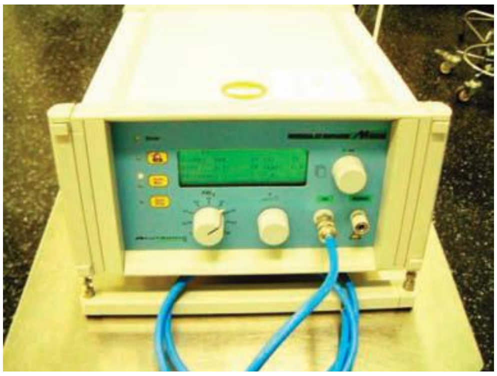


Fig 6. Mistral (Acutronic, Switzerland) automated high-frequency jet ventilator.

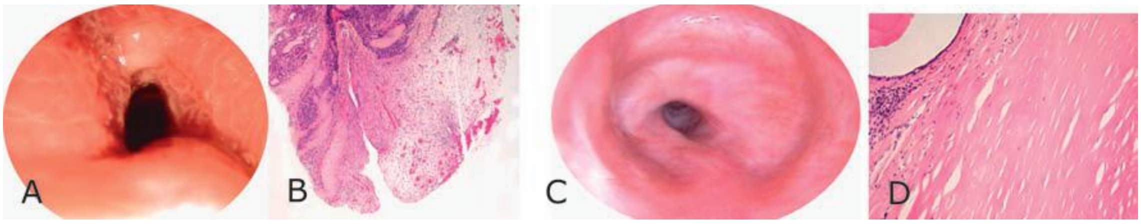


Fig. 7 A. Endoscopic and B. histological view of acute airway granulation; C. Endoscopic and D. histological view of 'mature' airway scar.

has the effect of dilating the stenosis, but also causes stripping of the mucosa in a longitudinal fashion. The rigid and flexible bronchoscopes are not ideal for assessing the glottis and immediate subglottic airway.

11. Stents

Charles Thomas Stent was a British dentist in the late nineteenth century. He developed dental impression material that was used as a template to support skin grafts for repair of oral trauma. Initially the term 'stent' was used to describe artificial structures for preserving the viability and function of tissue. Today, the term is used to describe devices for maintaining the patency of tubular structures, including the tracheo-bronchial tree. There are numerous devices for airway stenting made from either silicone or expandable metal. The metal stents can be uncovered, covered or partially covered (hybrid). Wire stents are made from either stainless steel or nitinol (a nickel and titanium memory alloy) covered with polyurethane, silicone or Teflon.

In benign and malignant disease, stents have been used to palliate the effects of large airway obstruction caused by extrinsic compression, endoluminal disease or loss of cartilaginous support. Indications in benign disease include long length stenoses, failed previous repair, patient co-morbidities that restrict reconstructive surgery or patient preference. Stents are also used temporarily following airway surgery. Although patients with metal stents enjoy immediate palliation of symptomatic tracheal stenosis, metal stents are associated with a high incidence of obstruction with granulation (Ranu and Madden, 2009). They are also susceptible to metal fatigue and fracture over time. Silicone stents probably have a lower incidence of biofouling but a higher migration rate unless sutured in place (Mace *et al*., 2005).

12. Mitomycin-C

Mitomycin-C (MMC) has been available since the 1960's as a systemic chemotherapeutic agent in the treatment of solid tumours. Mitomycin-C is a potent antibiotic derived from the Streptomyces caespitosus bacteria which can modify wound healing at the molecular level and has been used to interfere with post surgical scar formation. It was first reported in the ENT literature for the treatment of tracheal scarring after tracheal reconstruction in a small case series (Ward and April, 1998). A number of randomised prospective animal studies have shown impressive results in prevention of post-operative glottic and subglottic stenosis following surgery to the airway (Eliachar *et al*., 1999; Roediger *et al*., 2008; Smith and Elstad, 2009; Rahbar *et al*., 2000). Its use in airway surgery has become fairly routine, yet, there is no randomised controlled trials proving its efficacy. It is used in various concentrations and durations of application because optimum guidelines have not been firmly established. In the USA it has been used in the airway at concentrations of 0.4 mg/ml and in Europe it has been used at up to 2 mg/ml. The application is delivered topically, on a small swab, applied for anywhere between two and five minutes.

13. The endoscopic approach to post-intubation subglottic and tracheal stenosis

In clinical practice, the majority of patients with post-intubation upper airway stenosis have mature fibrotic airway scars with minimal evidence of ongoing airway inflammation. These patients typically have had an intubation episode in the relatively distant past and some of them have been erroneously treated for 'adult onset asthma' for some time before the diagnosis is secured. Less commonly, patients are referred within a few weeks of extubation with

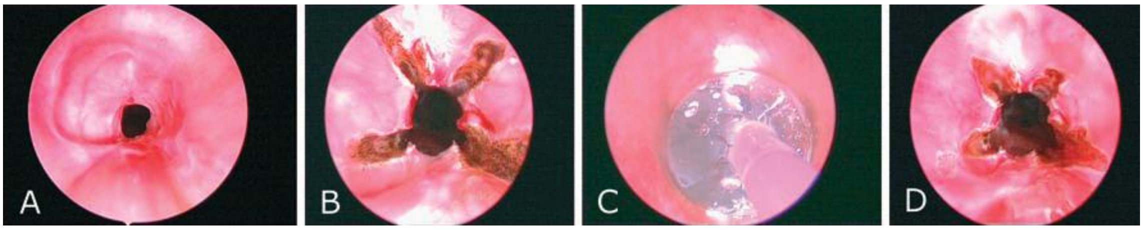


Fig. 8. In sequence, left shows tracheal stenosis, treated with radial cuts with the carbon dioxide laser, balloon dilatated and the end result on the right.

airway symptoms during the *active* fibro-inflammatory phase of tracheal injury (Fig. 7A-D).

These two presentations occur at different times within the natural history of the same disease process. The early phase of the post-intubation airway stenosis is characterised by mucosal ulceration and perichondritis followed by the formation of exophytic granulation tissue. As healing progresses, granulation tissue is gradually replaced with mature fibrotic tissue and the wound contracts giving rise to the classical picture of mature airway scar. It has been shown that inflammatory conditions in the airway do respond to intra-lesional steroids (Lorenz, 2003). Using suspension laryngoscopy and supraglottic jet ventilation, up to three millilitres of methylprednisolone acetate (40 mg/ml) can be injected into the stenosis. Radial cuts are then made into the stenosis with the carbon dioxide laser (8-10 watts continuous) delivered through the microscope using a line-of-sight technique (Fig. 8). The lesion is then dilated, using a pulmonary balloon dilator to the size of the adjacent normal airway. With more

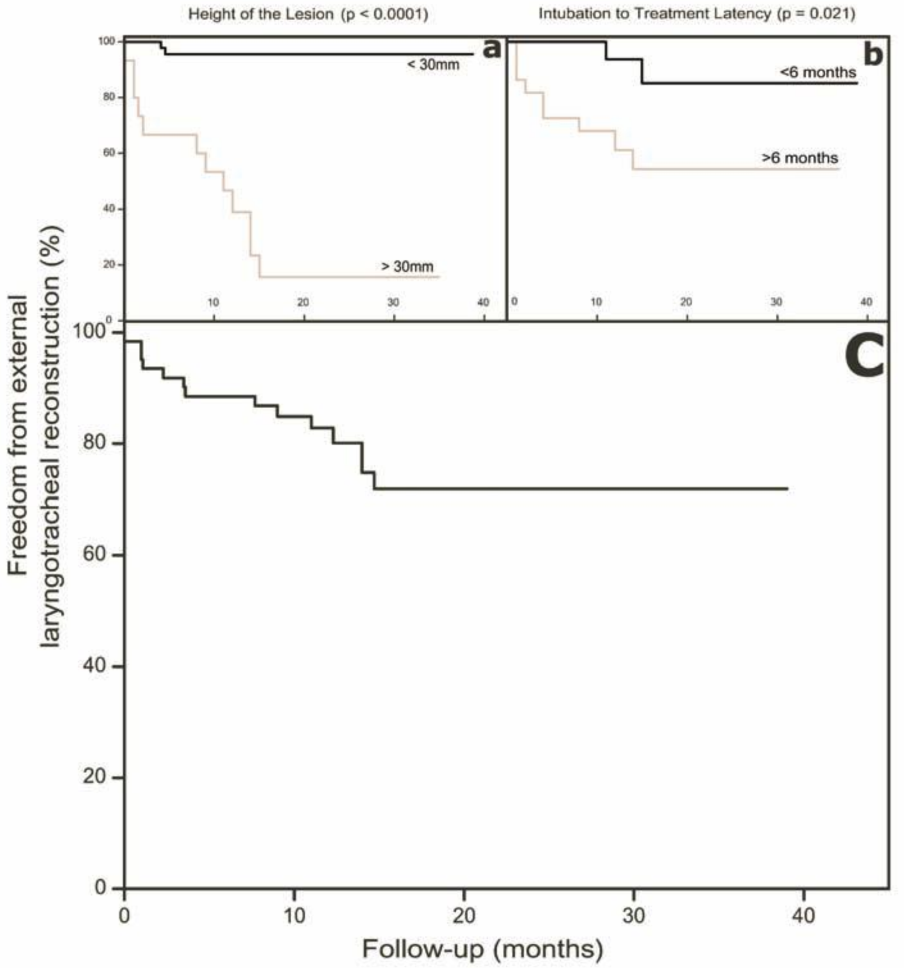


Fig. 9. Actuarial success rate of endoscopic surgery to treat postintubation tracheal stenosis (log-rank analysis). a: shows likelihood of endoscopic success as a function of the height of lesion; b: likelihood of success as a function of time from intubation to first treatment; c: overall success rate of endoscopic surgery (Nouraei *et al.*; 2007).

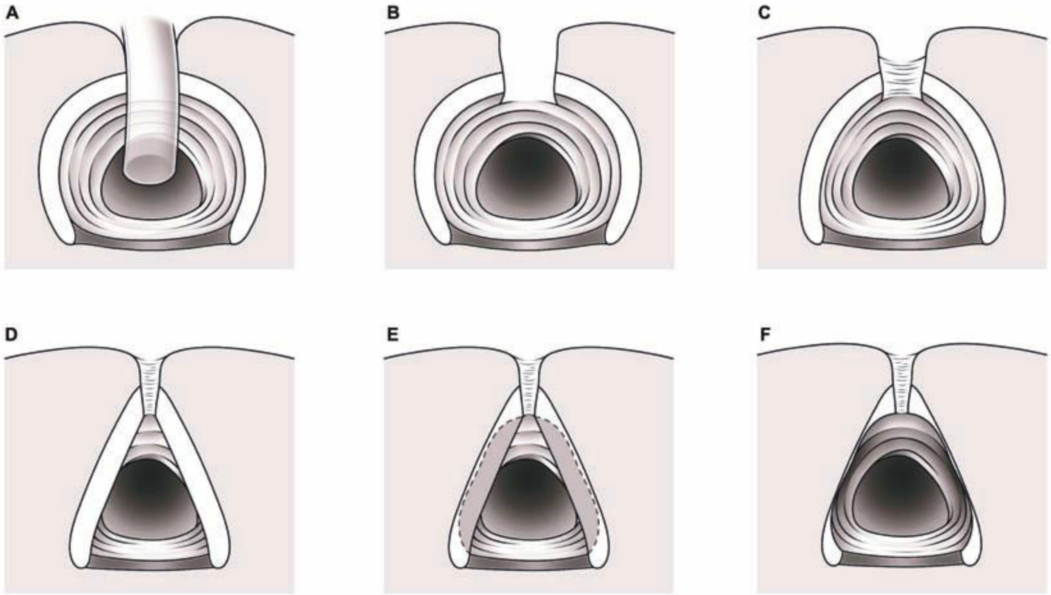


Fig. 10. Formation of 'lambdoid' deformity (D) of trachea. On decannulation, excessive scar contracture at the stoma draws in remnant tracheal cartilage rings (B-D). These encroaching cartilage rings can be ablated with a CO_2 laser (E) to produce a near normal airway (F).

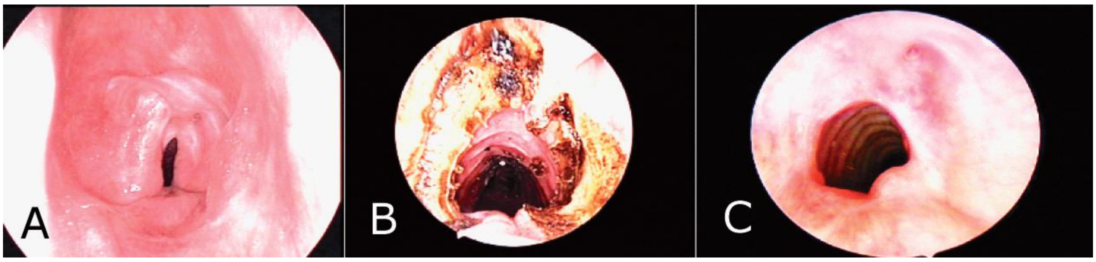


Fig. 11. Demonstrates a post-tracheotomy 'lambdoid' deformity, before, immediately post-laser and four weeks later.

mature and fibrotic lesions, intralesional steroids are of limited value. In these cases radial cuts into the lesion are followed by balloon dilatation and topical mitomycin-C application. Endoscopic surgery is repeated every three to four weeks.

Patients whose lesions prove recalcitrant to endoscopic therapy, and this usually becomes evident by the third procedure, should be treated with open laryngotracheal reconstruction or tracheal resection techniques. Also, where there is collapse and damage to the laryngotracheal cartilaginous structure, open surgical techniques should be considered, as endoscopic techniques are likely to fail. Figure 9 shows the overall success rate of the endoscopic approach to airway stenosis (n = 62) of 72%. Patients with a body mass index of greater than 45 all failed endoscopic airway surgery (Nouraei *et al.*, 2007)

14. Endoscopic tracheoplasty for treating tracheostomy related airway stenosis

A less common variant of post-ventilation tracheal stenosis is seen in a small number of tracheostomy patients. This is caused by over-resection or fracturing of anterior tracheal rings during tracheostomy. At decannulation, there is scarring and contracture at the stoma site which draws in the lateral ring remnants as a result of the wound contracture leading to a 'Lambda-shaped' stenotic deformity and airway compromise. The lesion usually extends over one to two tracheal rings with normal proximal and distal trachea (Nouraei *et al.*, 2007).

The trachealis is not involved and there is usually a small anterior bridge not contributing to the stenosis (Fig. 10).

Tracheal resection and anastomosis has been recommended for this condition (Grillo, 2003), but this

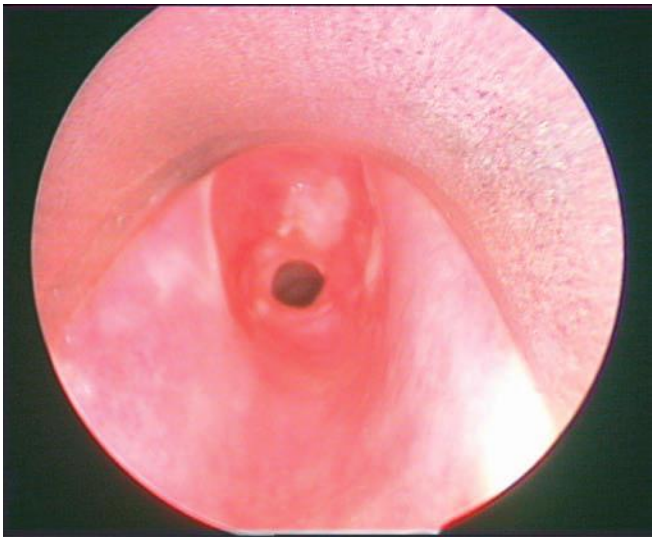


Fig. 12. Shows typical appearance of idiopathic subglottic stenosis.

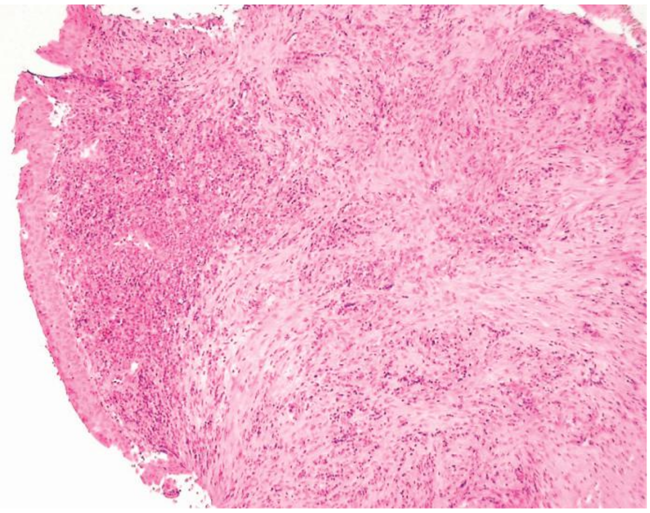


Fig. 13. HE staining (x25) of tissue biopsy of idiopathic subglottic stenosis. Respiratory epithelium (left) with stroma consisting of acute and chronic inflammation (polymorphs, histiocytes and plasma cells) and fibrosis.

is a major operation with associated morbidity and a small mortality rate.

The lesion can be treated using a CO_2 laser, delivering eight to ten watts continuously, deployed through a micromanipulator attached to the microscope using a 'line-of-sight' technique. The proximal and distal trachea is used as a guide to the limits of the resection and the collapsed cartilage is vaporised (Fig. 11). The resection can extend to the pre-tracheal fascia if necessary. A pulmonary balloon dilator may be used to expand the airway. The mucosa over the trachealis and the apex of the Lambda must be preserved because a circumferential injury with the laser will lead to further stenosis.

The patient can be discharged home the following day with a one week course of a broad spectrum antibiotic. The airway is reassessed under anaesthesia at three to four weeks. Any residual cartilage or granulation, encroaching into the airway, is removed. It is *unusual* for a patient to require more than three endoscopic procedures (Nouraei *et al.*, 2007), in such cases tracheal resection should be considered.

15. Idiopathic laryngotracheal stenosis

Idiopathic subglottic stenosis (ISS) is a rare, slowly progressive, fibro-inflammatory process of unknown aetiology which leads to narrowing of the airway in the subglottic region and usually involves the first and second tracheal rings. This form of airway stenosis should strictly be called laryngotracheal stenosis, as it involves the proximal trachea and extends up to the glottis (Fig. 12).

It occurs predominantly in women post-puberty, but has been reported in males (Benjamin *et al.*, 1997; Grillo *et al.*, 1993; Valdez and Shapshay, 2002; Dedo and Catten, 2001; Giudice *et al.*, 2003). The principal author (GS) has reviewed the first 50 patients with this condition in his series. Only one of them was male. All the patients were Caucasian and of European origin.

15.1. Aetiology

Patients with idiopathic subglottic stenosis have a highly reactive airway. The reason for the hyperreactivity of the airway is unknown. Embryologically, there does not appear to be any developmental significance to this anatomical site, although it is an area of intense immune activity. The condition does not affect or infiltrate the adjacent cartilaginous framework of the airway (Mark *et al.*, 2008).

15.2. Diagnosis

The diagnosis is by exclusion and our diagnostic criteria are included in Table 1. In each case, the anti-neutrophil cytoplasmic antibody (ANCA) and angiotensin converting enzyme (ACE) tests have to be repeated at intervals since neither test is 100% sensitive. Tissue for histology is also sent at *each* surgical procedure (Fig. 13).

Table 1. Diagnostic criteria for idiopathic subglottic stenosis.

Clinical features	Serum biochemistry
Female patient (males very rare)	Negative titres for:
No history of laryngotracheal injury	Angiotensin Converting Enzyme (ACE)
No endotracheal intubation or tracheotomy/no occurrence of exertional dyspnoea within two years of intubation/tracheotomy.	Antinuclear Antibody (ANA). Rheumatoid Factor (RF) Anti-Neutrophil Cytoplasmic Antibody (ANCA)
No thyroid/anterior neck surgery.	
No neck irradiation.	*Gross lesion morphology*
No caustic or thermal injuries.	The stenosis must include the subglottis
No significant anterior neck trauma (blunt or penetrating).	
No history of auto-immunity	*Histopathology* *
Negative history for vasculitis, formally ascertained through a vasculitis-specific systemic enquiry and semi-quantified using the Birmingham Vasculitis Activity Scale (BVAS).	**Exclusion of other pathological entities** (*e.g.*, tumours, vasculitides, amyloidosis…)
No history to suggest sarcoidosis or amyloidosis.	Fibrosis restricted to the epithelium with normal perichondrium/cartilage
	Mixture of granulation and fibrosis with a prominence of keloidal fibrosis

* This is established with a deep endoscopic biopsy at the time of first treatment.

Unfortunately, seven of the women in the author's series were treated for asthma for many years and were finally intubated for supposed asthma which had proven refractory to medical treatment. At the point of extubation, they were then diagnosed with post-intubation airway stenosis. An assumptive diagnosis of idiopathic subglottic stenosis was made in these patients based on the history, anatomy of the lesion and the fact that tests for other causes of airway stenosis had proven negative. In addition these patients were ventilated for very short periods, making the diagnosis of post-intubation LTS unlikely. Each of the 50 patients in this series has had histological tissue sent for analysis and the majority of patients have had this tissue tested for oestrogen and progesterone markers. All have proven negative. Although Shapshay (Valdez and shapshay, 2002) proposes a link with oestrogen, his group did not isolate oestrogen receptors in the tissue that they analysed.

15.3. Management: literature review

The management varies from crico-tracheal resection to repeated endoscopic procedures. Most series (Benjamin *et al.*, 1997; Grillo *et al.*, 1993; Valdez and Shapshay, 2002; Dedo and Catten, 2001; Giudice *et al.*, 2003) describe an initial assessment of the airway stenosis under anaesthesia with management using some form of dilatation. Other groups have undertaken endoscopic procedures using local mucosal flaps (Dedo and Sooy, 1984) whilst yet others have explored the use of Mitomycin-C (Valdez and shapshay, 2002) and steroid injections. None of these have proven therapeutic benefits. Table 2 illustrates all the published case series with more than 15 patients compared with our figures.

Grillo (Grillo *et al.*, 1993) published a series of 73 patients which he had treated with crico-tracheal resection. Only 65 of these patients turned out to have likely idiopathic subglottic stenosis. There were six failures in this series of crico-tracheal resection. Herb Dedo published a series of 52 patients (Dedo and Catten, 2001), seven of whom were treated with crico-tracheal resection and all failed.

Table 2. Review of the reported clinical series in the literature with more than 15 patients with idiopathic subglottic stenosis (ISS).

Authors	No. of patients	No. of patients treated	Period (years)	Endoscopically treated patients	No. of open-neck procedures	No. of failed open-neck procedures
Dedo and Catten	52	50	30	50	7	7
Grillo *et al.*	65	65	31	2	65	6
Giudice *et al.*	30	30	17	30	5	5
Valdez and Shapshay	16	14	12	14	2	0
Benjamin *et al.*	15	15	15	12	1	4
Sandhu *et al.* (unpublished)	55	55	7	45	10	0

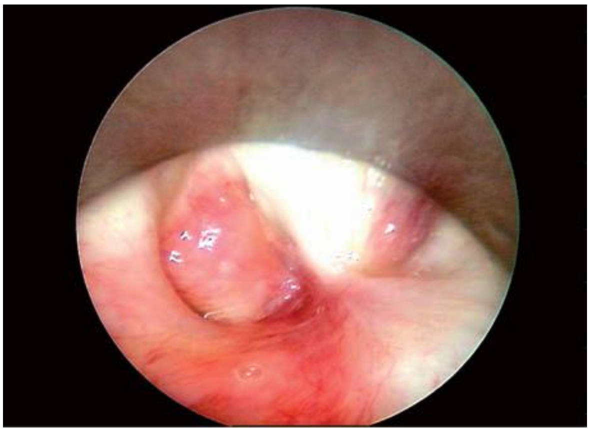


Fig. 14. Complete stenosis of the glottis extending to the tracheostomy in a patient treated aggressively for idiopathic subglottic stenosis.

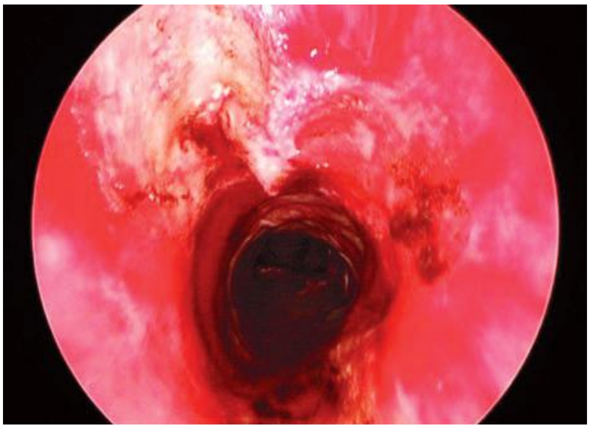


Fig. 15. Appearance of idiopathic subglottic stenosis after steroid injection, laser and balloon dilatation.

No other group has had a series as large as Grillo, nor have they been able to duplicate his success rate with crico-tracheal resection.

15.4. Management strategy

Injudicious attempts at endoscopic laser photo resection of the stenosis, pushing rigid bronchoscopes through, or stenting will almost invariably produce aggressive scar formation which can wholly close up the airway (Fig. 14).

Similarly, long-term tracheostomy is not a solution as the airway above the tracheostomy will stenose completely, resulting in aphonia.

The majority of our patients have elective endoscopic airway surgery once or twice a year as described below. This technique can also be applied to patients presenting for the first time with this condition, to treat the associated dyspnoea.

15.5. Surgical procedure

15.5.1. Transoral laser technique

Initially, an examination is carried out under anaesthesia with suspension laryngoscopy, supraglottic jet ventilation and rigid endoscopes to ascertain the dimensions of the lesion. Then, up to three millilitres of methylprednisolone acetate is injected into the lesion using an appropriate needle. The use of this steroid is empirical and is based purely on the grounds that there is an inflammatory component to the lesion.

The CO_2 laser is deployed through a micro-manipulator attached to the operating microscope. The

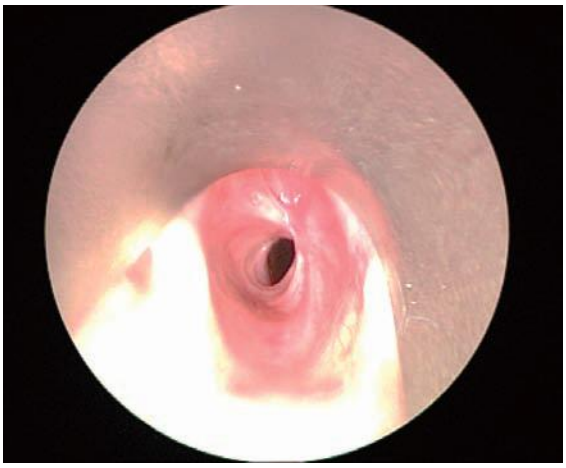


Fig. 16. Typical appearance of idiopathic subglottic stenosis extending up to vocal folds.

author does not advocate the use of KTP or diode laser since, compared with a CO_2 laser, both have a deeper collateral damage with further fibrosis of the coagulated scar tissue.

Three or four radial incisions are made into the lesion with a CO_2 laser set at eight to ten watts (Fig. 15). Following these radial cuts, the lesion is dilated to 15-16 mm using a pulmonary balloon dilatation system. A deep-tissue biopsy is taken at this stage, using microcup forceps, and haemostasis is secured using topical adrenaline applied with a neurosurgical pattie soaked in 1:1,000 adrenaline.

15.5.2. Transcervical open surgery

Detailed description of management by external approach is beyond the scope of this volume. Briefly, our approach to open surgery differs from the orthodoxy of crico-tracheal resection and anastomosis for the following reasons:

- Idiopathic subglottic stenosis is primarily a mucosal disease which overlies healthy perichondrium and cartilage (Mark *et al*., 2008).
- No one has been able to duplicate the excellent cure rates reported by Grillo's group using crico-tracheal resection.
- Since idiopathic subglottic stenosis mainly affects the female population, there is a concern that the conventional crico-tracheal resection is likely to leave these patients with 'male-type' voices after the surgery (Smith *et al*., 2008).
- Crico-tracheal resection conceptually treats this condition as a benign neoplasm.

In our series, the disease often extended up to the glottis (Fig. 16) and it is difficult to conceive how a resection could be performed within millimetres of the vocal folds without leaving damage in this area.

The author therefore uses the following technique:

- Laryngofissure and posterior cricoid split is performed;
- The majority of the stenosed mucosa is removed;
- A piece of costal cartilage is placed as a 'spacer' to expand the posterior cricoid split (similar to the open management of dense inter-arytenoid scar tissue, Fig. 17);
- A closed laryngeal stent, covered with a superficial skin graft (epidermal surface against stent), is held in place with a single, strong, mono-filiament suture.

A temporary tracheostomy is required because there is no airway through the larynx once the laryngofissure is closed. Two weeks later, the stent is removed endoscopically, followed by the closure of tracheostomy. Keratinocytes colonise the parts

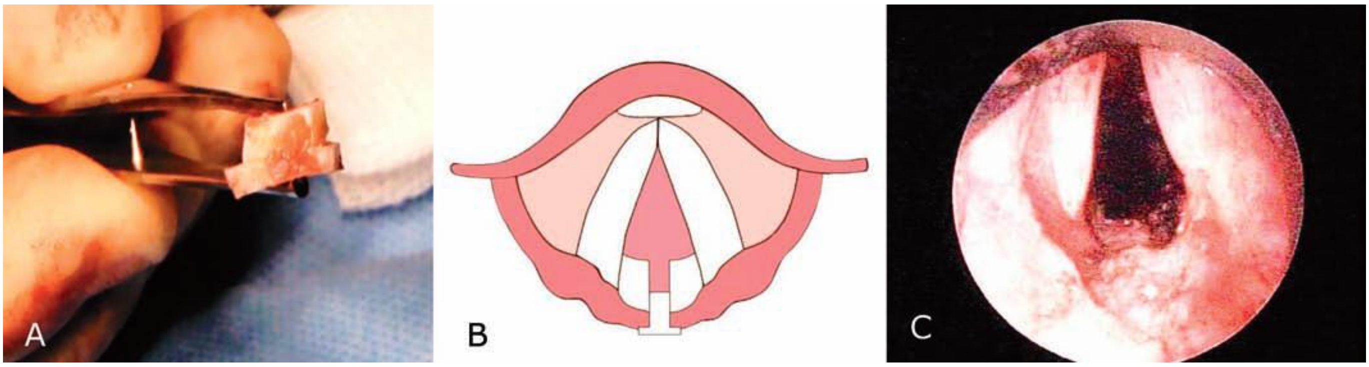


Fig. 17. Posterior rib graft (as a 'spacer'), is the only solution to separating thick interarytenoid scar. Case from Fig. 16 above, following successful treatment (right).

of the airway where the diseased mucosa was excised and inhibit restenosis. Keratosis is generally not a problem and can be managed with segmental, staged, lasering.

16. A proposed system for assessing adult patients with laryngotracheal stenosis

It is possible to accurately calculate the cross-sectional area of the airway at the site of a stenosis (Nouraei *et al*., 2006) but the most important outcome is the improvement in the patient's symptoms and also the impact on his or her quality of life. For the purpose of documenting the grade of a stenosis, the Myer-Cotton system is already widely used and imaging and per-operative assessments can be used to measure the length of the damaged airway.

A simple system for documenting the functional outcome of adult laryngotracheal stenosis is proposed (Form A). It consists of four domains of airway:

- (A), providing a description of the status of the airway;
- (D), dyspnoea, which is an adaptation of the Medical Research Council (MRC) dyspnoea grading system;
- (V), voice;
- (S) swallowing.

The last three components are scored by the patient while airway status is documented by the clinician. All parts of the system have a 1-5 ordinal scale. The airway (A) domain is reported by the surgeon and is as follows:

Airway status (A)

1. No airway prosthesis
2. Intraluminal airway prosthesis (stent)
3. Tracheostomy or T-tube dependent, patient voices
4. Tracheostomy-dependent, patient does not voice
5. Death as a result of a direct complication of airway disease

The dyspnoea (D), voice(V) and swallowing (S) domains are scored by the patient before and after treatment and are shown in Form A. Outcomes are documented as subscripts, for example A_1-D_2-V_1-S_1 and should not be combined to form a single number. This information can be tabulated or plotted to provide a visual temporal treatment map, charting patient progress through treatment. It can also yield time-dependent variables, *e.g.* time to the attainment of a prosthesis-free (A_1) or tracheostomy-free (A_1 or A_2) airway from the outset of therapy, for actuarial analysis.

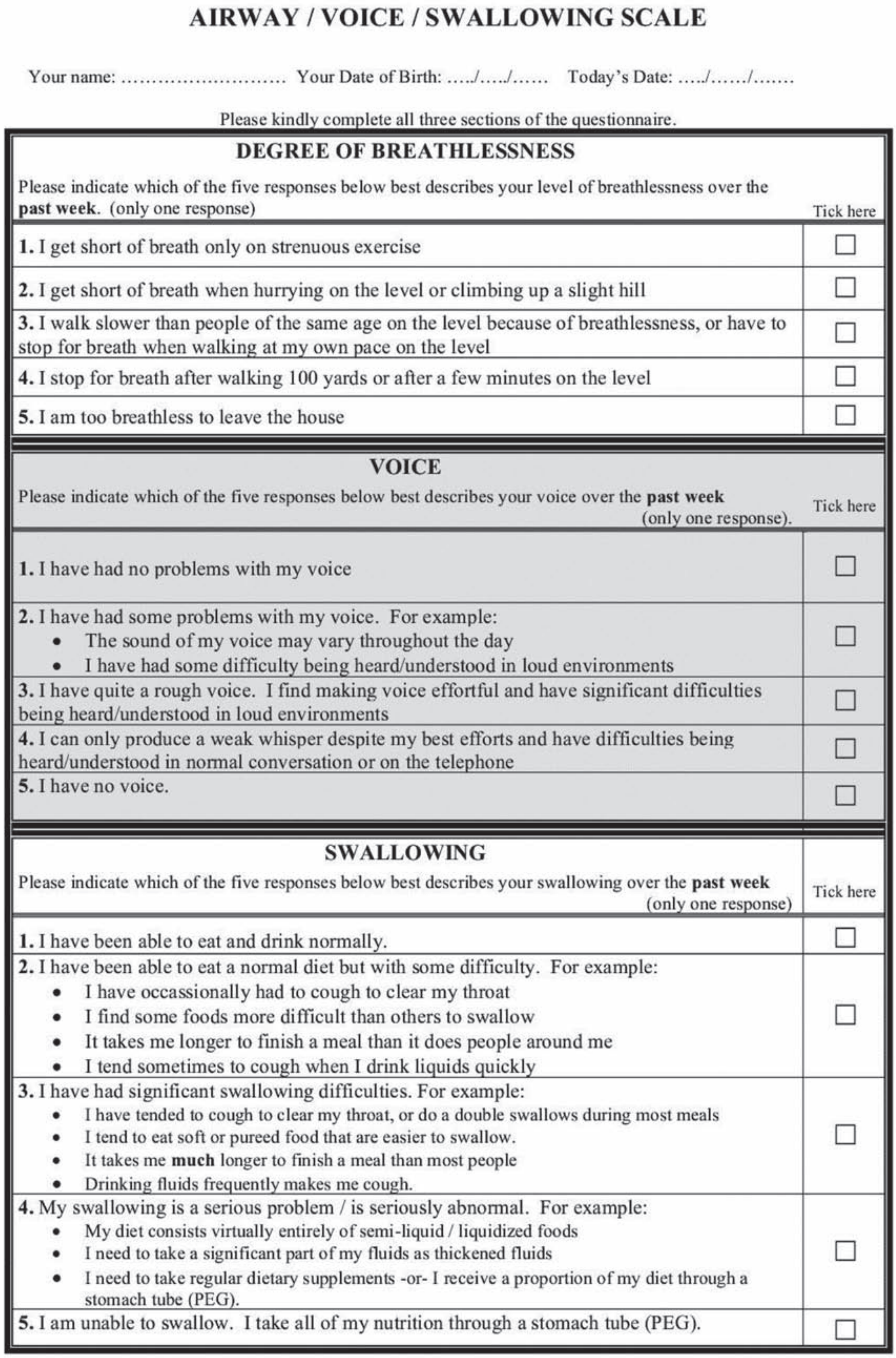
17. Outcome measure

The proposed system provides a simple patient-centred method of assessing the outcome of patients with laryngotracheal stenosis throughout treatment through the use of simple-to-use ordinal scales. The MRC scale which forms the 'D' component of the system has been validated for this purpose and is already widely used for evaluating dyspnoea (Nouraei *et al*., 2008; 2009). The one difficulty with this MRC dyspnoea scale is its application to patients who have tracheostomies. The 'A', 'V' and 'S' components have been derived through studying other voice and swallowing scales and in consultation with laryngologists and speech and language therapists and still require validation. They are based on the experience of evaluating the range of functional impairments that were observed in the first 400 patients, with laryngotracheal stenosis, who were treated by the senior author (level IV evidence).

For a more detailed assessment of airway, voice and swallowing symptoms and morbidity, the Clinical COPD Questionnaire (CCQ) (Van der Molen *et al*., 2003), the Voice Handicap Index-10 (VHI-10) (Deary *et al*., 2004) and the Eating Assessment Tool (EAT-10) (Beladsky *et al*., 2008) can be used. These are all validated, 10-item, patient-administered, symptom severity instruments. The Short Form 36 health survey questionnaire (SF-36) can be used to assess changes in patient quality of life in response to airway treatment (Ware and Sherbourne, 1992). It is proposed to administer the SF-36 at least six months after the conclusion of airway therapy. It is hoped that this proposed (ADVS scoring) system could lead to a more uniform reporting of airway reconstruction outcomes for easier comparison and combination of treatment results for audit, research and meta-analysis purposes. Table 3 lists assessment and outcome measures for all future patients referred to the Airway Reconstruction Unit.

18. Conclusion: The future of laryngotracheal stenosis management

The repair of long lengths of airway defects remains a major problem for clinicians. Up to six cm of trachea can be resected (Grillo *et al*., 2003)



AIRWAY / VOICE / SWALLOWING SCALE

Your name: ……………………… Your Date of Birth: …../…../…… Today's Date: …../……/…….

Please kindly complete all three sections of the questionnaire.

DEGREE OF BREATHLESSNESS Please indicate which of the five responses below best describes your level of breathlessness over the **past week**. (only one response)	Tick here
1. I get short of breath only on strenuous exercise	☐
2. I get short of breath when hurrying on the level or climbing up a slight hill	☐
3. I walk slower than people of the same age on the level because of breathlessness, or have to stop for breath when walking at my own pace on the level	☐
4. I stop for breath after walking 100 yards or after a few minutes on the level	☐
5. I am too breathless to leave the house	☐

VOICE Please indicate which of the five responses below best describes your voice over the **past week** (only one response).	Tick here
1. I have had no problems with my voice	☐
2. I have had some problems with my voice. For example: • The sound of my voice may vary throughout the day • I have had some difficulty being heard/understood in loud environments	☐
3. I have quite a rough voice. I find making voice effortful and have significant difficulties being heard/understood in loud environments	☐
4. I can only produce a weak whisper despite my best efforts and have difficulties being heard/understood in normal conversation or on the telephone	☐
5. I have no voice.	☐

SWALLOWING Please indicate which of the five responses below best describes your swallowing over the **past week** (only one response)	Tick here
1. I have been able to eat and drink normally.	☐
2. I have been able to eat a normal diet but with some difficulty. For example: • I have occassionally had to cough to clear my throat • I find some foods more difficult than others to swallow • It takes me longer to finish a meal than it does people around me • I tend sometimes to cough when I drink liquids quickly	☐
3. I have had significant swallowing difficulties. For example: • I have tended to cough to clear my throat, or do a double swallows during most meals • I tend to eat soft or pureed food that are easier to swallow. • It takes me **much** longer to finish a meal than most people • Drinking fluids frequently makes me cough.	☐
4. My swallowing is a serious problem / is seriously abnormal. For example: • My diet consists virtually entirely of semi-liquid / liquidized foods • I need to take a significant part of my fluids as thickened fluids • I need to take regular dietary supplements -or- I receive a proportion of my diet through a stomach tube (PEG).	☐
5. I am unable to swallow. I take all of my nutrition through a stomach tube (PEG).	☐

Form A. The proposed symptom scoring system for the Airway Reconstruction Unit. The Dyspnoea component (top) is based on the Medical Research Council dyspnoea scale and has already been validated for adult airway stenosis (Nouraei *et al*., 2008; 2009).

Table 3. Proposed outcome assessment in airway stenosis in the future.

Level of assessment	Outcome measures
Anatomy	Myer-Cotton scale for cross-section narrowing
	Cranio-caudal extent (vertical height) of the lesion
	Distance from glottis
Flow physiology	Spirometry
	Flow-volume loop
Exercise physiology	Incremental shuttle walk test
	Cardiopulmonary exercise testing (CPET)
Airway status	A domain of ADVS
Symptoms – dyspnoea and effort intolerance	D domain of ADVS
	Clinical COPD Questionnaire (CCQ)
Symptoms – voice	V domain of ADVS
	VHI-10
Symptoms – swallowing	S domain of ADVS
	EAT-10 Instrument
Quality of life	Short Form 36 Health Survey Questionnaire (SF-36)

in the adult with primary anastomosis. The repair of tracheas beyond this length or where there has been failed previous resective surgery has proven difficult. Tissue engineering and tracheal allotransplantation are two techniques that are being explored and hold promise for the future. Similarly, laryngeal transplantation may be the solution to restoring the airway where this organ is damaged beyond repair.

Advances in biotechnology may provide the solution to difficult problems such as long-length tracheal replacement and tracheomalacia. Biocompatible and biointegratable scaffolds that mimic the mechanical properties of tracheal cartilage could be used to provide shape to muscle flaps for use as tracheal replacements. Biointegratable stents could be an even simpler solution for the management of airway stenosis.

Recently, laser cartilage reshaping has been carried out for cartilagenous deviated nasal septum and for protruding ears (Chapter 61,62,63). The new shape is achieved with thermal relaxation of stress which maintains the original shape of the cartilage. The procedure is non-surgical. Laser cartilage reshaping may have a role to play in LTS caused by collapse of tracheal rings.

Until these technologies are proven and widely available, prevention of laryngotracheal airway compromise is essential. This does not just mean the early recognition and treatment of associated diseases, but an understanding of the risk factors for airway injury on the Intensive Care Unit. This requires appropriate sizing of endotracheal and tracheostomy tubes, monitoring cuff pressures and early change to trachesotomies in patients destined for prolonged ventilation, to avoid damage to the glottis.

Part B: Laryngotracheal compromise due to chronic inflammatory disease

(see Chapter 56 for Lasers in chronic tropical inflammatory diseases in Otolaryngology)

19. Introduction

Until the first half of the twentieth century chronic inflammatory otolaryngological conditions were usually infective in nature. Infections such as tuberculosis, syphilis and diphtheria could cause airway compromise either through a space occupying effect or through resultant scarring. Although the arrival of antimicrobial drugs and vaccination reduced the incidence of these conditions, other forms of chronic inflammatory conditions, often auto-immune, were recognised. The effects of Wegener's granulomatosis, sarcoidosis and mucous membrane pemphigoid on the laryngotrachel airway are discussed below. Some chronic inflammatory conditions show demographic prevalence, these are covered in Chapter 56, **Lasers in chronic tropical inflammatory diseases in Otolaryngology**.

20. Wegener's granulomatosis

Wegener's granulomatosis (WG) is a multi-system inflammatory disease with an underlying vasculitis involving small and medium sized vessels. There is associated granuloma formation (Fig. 18). The sites

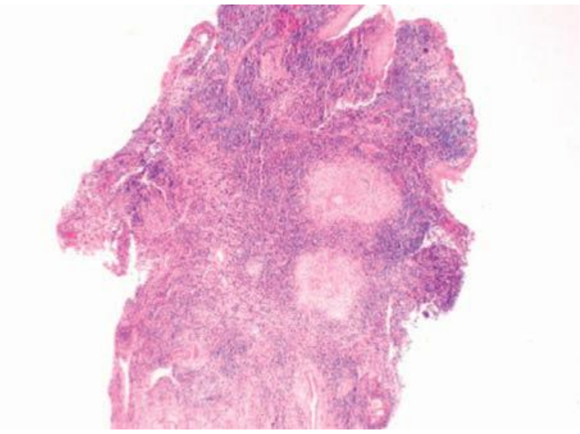


Fig. 18. HE slide (x25) of respiratory mucosa showing granulomas.

of predilection are the upper and lower respiratory tracts and the kidneys.

20.1. Literature review

Wegener's granulomatosis is believed to have been first described in 1931 by Klinger, who reported a patient with destructive sinusitis, nephritis and disseminated vasculitis. In 1936, Wegener clearly defined the disease as a distinct clinical and pathological entity. However, a Scottish otolaryngologist, Peter McBride may well have been the first to describe the condition in 1897 in the British Medical Journal in a paper entitled ' photographs of a case of rapid destruction of the nose and face' (Friedmann, 1982).

20.2. Otorhinolaryngological symptoms

More than 80% of patients with Wegener's granulomatosis experience rhinological and 20-40% experience otological morbidity at some point during their affliction (Srouji *et al*., 2007). Seventeen to 23% of patients with Wegener's granulomatosis develop laryngotracheal stenosis (Langford *et al*., 1996). Sometimes, localised narrowing of the airway may be the only presentation of WG. Laryngotracheal inflammation and narrowing does not uniformly respond to systemic immunosuppresives and may persist despite adequate disease control in other organ systems (Langford *et al*., 1996). This type of focal disease may make it difficult to justify the use of systemic corticosteroids and cytotoxic drugs.

20.3. Diagnosis

The diagnosis of Wegener's granulomatosis is often made on clinical presentation when the patient has had the relevant symptoms for a prolonged period of time. As well as the otolaryngological manifestations already mentioned, patients usually also have involvement of the lungs and kidneys and there may even be an element of renal failure.

The presence of a positive ANCA (antinuclear cytoplasmic antibody) test may aid in the diagnosis. However, a positive result is not conclusive, likewise, a negative ANCA result does not necessarily excludes the diagnosis. A firm diagnosis of Wegener's granulomatosis can be made by a biopsy of suspicious lesions (demonstrating granulomatous inflammation) in conjunction with positive serological analysis. However, it must be emphasised that up to 20% of patients with untreated active Wegener's granulomatosis lack positive ANCA result (Seo and Stone, 2004) or may be positive later on in the disease history.

20.4. Management

Intra-lesional corticosteroid injections, radiate lesion cuts, and dilatation will treat the majority of new stenoses involving the larynx, trachea and bronchi due to Wegener's Granulomatosis (Fig. 19) (Nouraei *et al*., 2008). Tracheostomy and long-term stents can lead to airway complications which are difficult to treat (Grillo *et al*., 1995; McCaffrey *et al*., 1993).

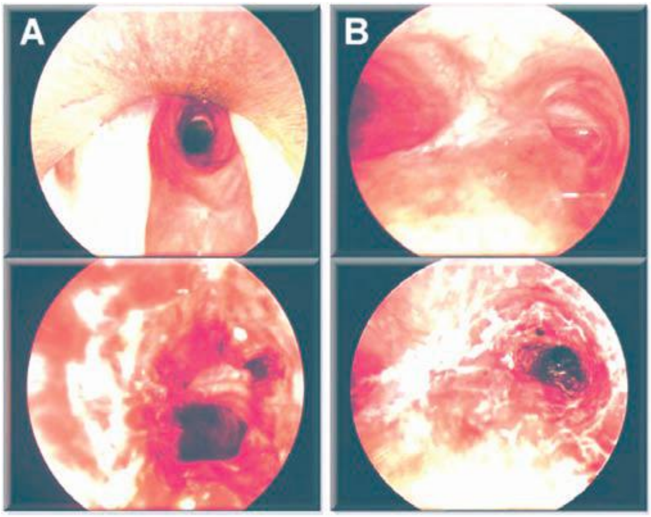


Fig 19. A: Intra-operative results of treating a tracheal lesion; B: Intra-operative results of treating a bronchial lesion. The white streaks are displaced methylprednisolone (Nouraei *et al*., 2008).

21. Laryngotracheal sarcoidosis

21.1. Literature review

Cesar Boeck of Christiania, Denmark was the first to use the word 'sarcoid' in 1899, and described the multi-system nature of the disease (Black, 1973; Newman *et al.*, 1997). He mentioned the clinical similarity to a previous case described by Jonathan Hutchinson of London in 1898 of Mortimer's Malady in a female patient, Mrs Mortimer, who had generalised skin lesions and swelling of the bridge of the nose.

21.2. Prevalence

Sarcoidosis has a world-wide distribution and can affect any race, ethnicity, gender or age group. Typically, it is found in patients aged 20-40 years and has a female to male ratio of 2:1, with a predilection for black African Americans (Newman *et al.*, 1997). Otolaryngological involvement occurs in < 3% of cases and can occur in isolation as the only initial presenting symptom or can represent progression of this systemic disease (Judson *et al.*, 1999). Laryngeal pathology is often overlooked and many authors have suggested that if actively sought, a high incidence would be found. Laryngeal sarcoidosis thus has a variable incidence reported between 1% and 5% (Devine, 1965; Krespi *et al.*, 1987; Ellison and Canalis, 1986). Anatomically, laryngeal sarcoid has a predilection for the supraglottic region, particularly the epiglottis, aryepiglottic folds and arytenoids (Fig. 20).

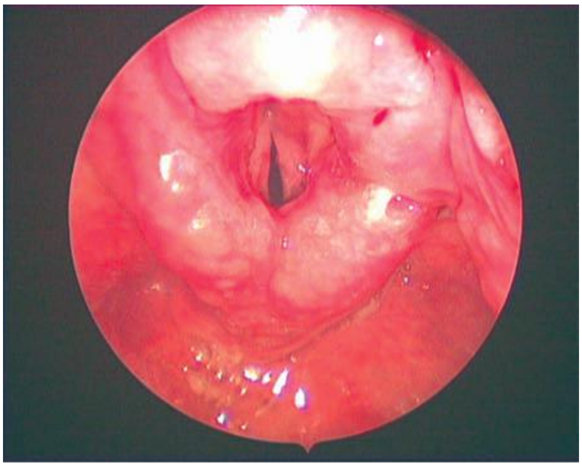


Fig. 20. Diffuse swelling of the surpaglottic larynx typical of sarcoidosis.

21.3. Pathophysiology

The pathophysiology behind sarcoidosis remains obscure and numerous infectious, chemical or occupational agents have been postulated as inducing disease. Abnormal auto-immune mechanisms are seen in sarcoidosis such as the inability to mount or maintain delayed type hypersensitivity reactions (Gallivan *et al.*, 1993). This forms the basis for a negative tuberculin test that is characteristically seen. Current hypotheses propose sarcoidosis to occur in generally susceptible individuals through alterations in immune responses after exposure to various 'triggering' agents.

21.4. Clinical presentation

The macroscopic appearance of the supraglottis is diffusely thick, oedematous and characteristically pale or pink in colour. These features are considered pathognomonic for this condition (Devine, 1965). Although exophytic, polypoidal, nodular and granulating lesions have been described, these are less common (Krespi *et al.*, 1987). Isolated involvement of the glottis is exceedingly rare (Yanardag *et al.*, 2006). This may be explained by the paucity of lymphatics draining the glottis and that sarcoidosis is a disease of the reticulo-endothelial system (Dean *et al.*, 2002). Decreased vocal cord mobility is a feature seen with diffuse laryngeal invasion. True vocal cord paralysis can also occur as a result of perineural invasion or multiple cranial nerve polyneuritis (Devine, 1965). Laryngeal disease tends to progress slowly with a relapsing and remitting course. The disease may ultimately 'burn out' in later stages. Symptoms are recognised when granulomatous lesions are present; however, they may persist despite remission, due to subsequent fibrosis.

21.5. Diagnosis

The diagnosis of sarcoidosis depends on the presence of typical clinical features and *non-caseating* granulomatous inflammation on biopsy of an affected organ (Fig. 20), along with the exclusion of other known causes of granulomas, including tuberculosis, leprosy, syphilis and fungal disease.

21.6. Management

Traditionally, high-dose systemic steroids have been recommended as the first-line treatment of laryngeal sarcoid (www.icnarc.org). Surgery, such as endo-

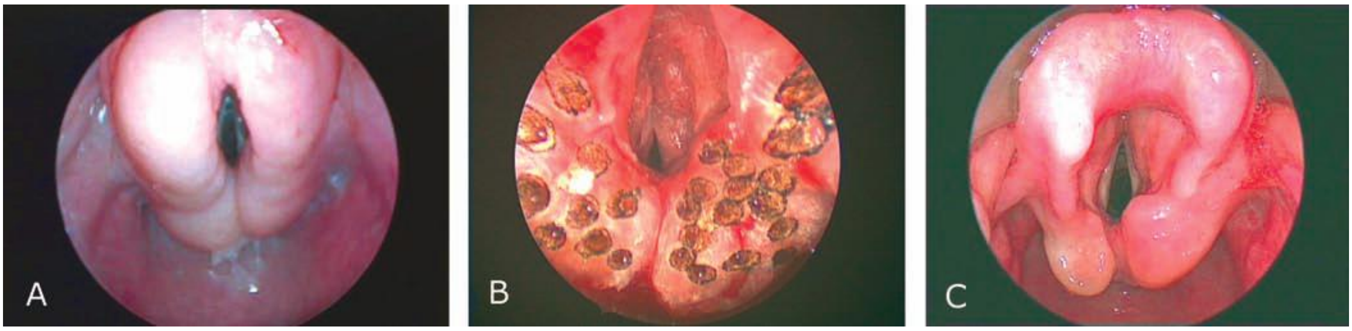


Fig. 21. Endoscopic views of laryngeal sarcoid. Preoperative (left) and three weeks post-surgery (right). Peroperative view (middle) demonstrating appearance after steroid injection and 'pepper-pot' laser photoreduction (Butler *et al*., 2010).

scopic laser reduction, has been used as a last resort where conservative therapy has failed. The authors' technique for managing laryngeal sarcoidosis has led to a reduction or cessation of systemic steroids and decannulation in the majority of cases (Butler *et al*., 2010).

The procedure is performed under general anaesthesia using suspension laryngoscopy and a supraglottic or subglottic high frequency jet ventilation technique. The larynx and airway are visualised using a combination of microscope and a rigid endoscope.

A biopsy of the laryngeal lesion is routinely performed for histology and microbiological studies. Up to three ml of Methylprednisolone acetate (depomedrone), at a concentration of 40 mg/ml, is injected at multiple sites into the lesion using a standard microlaryngoscopy injection needle. The end point of injection should produce almost complete blanching of the lesion.

Following infiltration, the lesion is reduced using the Carbon Dioxide laser at a continuous setting of 8-10 watts. Intralesional steroids help control localised disease in the medium to long term, however immediate airway improvement is achieved through lesional volume reduction using the laser. The laser is delivered via a micromanipulator attached to the microscope. Any pedunculated lesions encroaching into the airway are excised with a small arc using the laser. It is important not to create a circumferential injury in or around the laryngeal inlet as this has the potential for stenosis through scarring. Multiple narrow pits are created with the CO_2 laser, separated by approximately two mm, and extending to the depth of the lesion. This 'pepper pot' pattern is mucosa sparing, but reduces the volume of the disease both immediately and as healing takes place by scarring and contracture (Fig. 21). Most patients require on average of two treatments (range one to four) separated by three to four weeks.

22. Mucous membrane pemphigoid

Mucous membrane pemphigoid (MMP) is an autoimmune disorder characterised by subepithelial bullae. Basement membrane components have been identified as targets for the autoantibodies. The condition may involve the oral cavity, conjuctiva, pharynx, larynx, oesophagus, genitourinary tract and anus. Patients may present with one or several mucosal sites invloved. The involved areas are very sensitive to trauma and often desquamate with subsequent scarring.

22.1. Diagnosis

Diagnosis of MMP is based on the clinical findings, histology and immunofluorescence studies. Histology reveals subepithelial blisters with a variable inflammatory cell infiltrate. Direct immunofluorescence of lesional mucosa will reveal linear deposits of antibodies along the basement membrane (Fine *et al*., 1984).

22.2. Management

The condition should be managed by a multidisciplinary team. Systemic corticosteroids are the agents of choice for initial treatment and steroid sparing agents are introduced for longterm maintenance. Active laryngopharyngeal disease can lead to scarring and stricture of the pharynx and supraglottic larynx. However, surgery during the active phase of this disease is not advised due to the delicate and friable nature of the mucosa. Even minor sur-

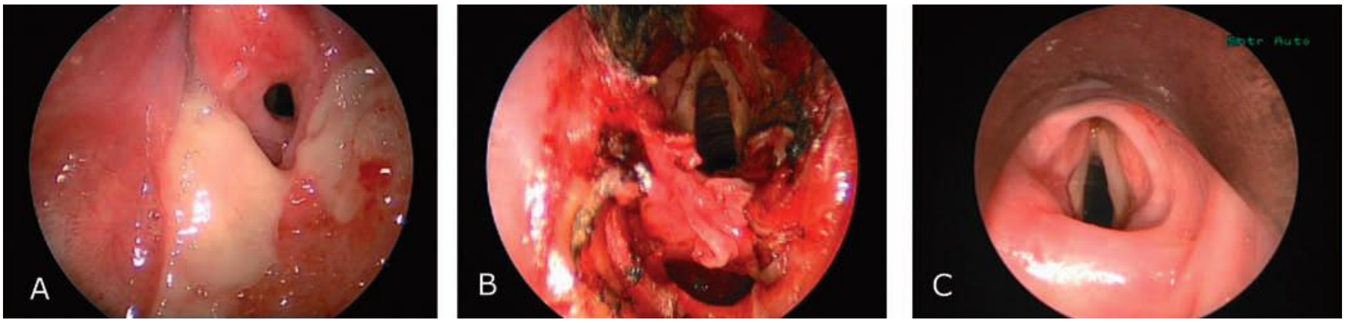


Fig. 22. Result of MMP (left) involving hypopharynx and supraglottic larynx. The airway opening is formed by the mucosa of the tip of the epiglottis which has fused with that of the aryepiglottic folds. The opening towards the oesophagus lies immediately behind it, but is concealed by scar tissue. The laryngeal and oesophageal inlets are visible (centre) following endoscopic laser surgery. The appearance after two months (right).

gical trauma can lead to bleeding and swelling in an already compromised airway. The airway compromise should be managed with a tracheostomy while medical treatment is taking place. Following control of the disease, scar and strictures in the upper aerodigestive tract often respond to endoscopic surgery (Fig. 22) using lesional steroids, releasing cuts with the CO_2 laser and gentle dilatation.

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MCQ – 16. Endoscopic laser management of the compromised laryngotracheal airway

1. Of all the cases of adult Laryngo-Tracheal-Stenosis (LTS), intubation history in the ITU is present in
    a. Most of them
    b. around half of them
    c. At least in one third of them
    d. In excess of 75%
    e. The number varies from centre to centre

2. In paediatric population, the most common aetiology for LTS is
    a. Accidental corrosive ingestion / inhalation
    b. Congenital
    c. Iatrogenic
    d. Prolonged intubation
    e. Premature birth

3. In adults, LTS can result in
    a. Breathlessness
    b. Failure to thrive
    c. Stridor
    d. Hoarseness
    e. All of the above

4. Prolonged intubation in the paediatric population most commonly results in stenosis of
    a. Posterior commissure
    b. Posterior commissure and posterior subglottis
    c. Subglottis
    d. Anterior and posterior commissure
    e. Bilateral vocal cord paralysis

5. Amongst a number of risk factors involved in causing LTS following prolonged intubation, the most important one are
    a. Lack of ITU facility
    b. Duration of intubation
    c. Pressure necrosis due to over inflation of the cuff
    d. Co-morbidity such as chronic bronchitis, diabetes, hypotension
    e. Patient movement and agitation

6. Accurate *objective* sizing of the LTS is carried out by
    a. Pulmonary function tests
    b. CT scan
    c. High definition CT scan
    d. Spirometry and flow-volume loop
    e. Leaks around different sized endotracheal tubes (Myer-Cotton grading system)

7. The most suitable laser for transoral endoscopic management of LTS is
    a. CO_2 laser
    b. KTP laser
    c. Ho:YAG laser
    d. Diode laser
    e. Pulse dye laser (PLD)

8. Mitomycin-C (MMC) is used
    a. For discouraging formation of fibrosis at a molecular level
    b. By injecting intra-lesionally to prevent multiplication of fibroblast
    c. Routinely in the airway surgery for LTS
    d. By applying topically with soaked pledgets
    e. Only in adult LTS on account of its toxicity in paediatric population

9. External approach should be considered in airway stenosis
    a. When endoscopy has failed to achieve adequate airway after three attempts
    b. In patients with co-morbidity
    c. Non-compliance for endoscopic staged surgery
    d. Right at the outset, when stenosed segment is longer than 6 cms.
    e. In idiopathic subglottic stenosis mainly occurring in female patients

Chapter 17

Transoral endoscopic management of acute obstruction caused by laryngeal malignancy

V. Paleri, S. Penney, A. Chishti and J. Tapon

1. Introduction

Airway obstruction caused by laryngeal malignancy is one of the most dramatic emergencies in otolaryngologic practice. In the vast majority of cases, once the diagnosis has been made, rapid intervention is required to manage the obstruction and reestablish a functional airway. The choice of management will be dictated by several factors. Some of them are patient related, but more importantly, most are largely dependent upon the expertise and the facilities available at the treating institution. This chapter covers in detail the indications, techniques and limitations of transoral endoscopic debulking of obstructing laryngeal tumours and presents a balanced view of the benefits and risks involved.

2. Background

The conventional and time-honoured management of patients presenting with acute airway obstruction secondary to laryngeal malignancy is tracheostomy. Some centres have also advocated emergency laryngectomy (see below).

2.1. Tracheostomy

Tracheostomy has a merit of securing the airway rapidly, under local or general anaesthesia. It can be undertaken in most medical settings, with readily available instrumentation. Although at times challenging, it does not require specialised high-end training. Tracheostomy is therefore a method of choice in those patients who present with advanced obstructing disease. Subsequent definitive management usually involves total laryngectomy, chemoradiation, palliation or a multimodal treatment strategy. Organ preservation surgery is usually not an option for these patients.

Presence of stoma created during emergency tracheostomy does influence future definitive surgical management. Total laryngectomy must be planned in such a way that the stoma and the skin around it is meticulously removed en block with the main tissue. A permanent stoma is fashioned in a virgin tissue. Further implications of emergency tracheostomy are covered in Box 1.

Tracheostomy is also often undertaken for palliation of the obstructed airway. Such tracheostomised patients have a poor quality of life and they require an ongoing care which has significant resource implications. A competent nursing care may not always be available, entailing periodic journeys, some distance away. Stomal spread also may occur, with bleeding and foetor.

2.2. Emergency laryngectomy – peristomal disease

Some surgeons consider that peristomal malignancy occurs due to implantation of neoplastic seeding in mechanically disrupted normal tissue at the site of previous tracheostomy (Clayman *et al.*, 1993) 'Emergency laryngectomy' is undertaken within 24 hours of presentation by surgeons who support this view. Narula *et al.* (1993) compared the incidence

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Box 1. Implications of tracheostomy

1. Predisposition to complications, *e.g.*; aspiration pneumonitis, that may delay definitive treatment.
2. Impact on decision making for definitive management.
3. Interference with interpretation of radiologic imaging.
4. Interference with delivery of radiation therapy, especially if performed during treatment course.
5. Need to modify surgical resection to include tracheostomy site.
6. Increased nursing input.
7. Increased in-patient stay.
8. Special equipment for home care.

of peristomal disease in patients undergoing emergency laryngectomy versus delayed laryngectomy. They concluded that stomal recurrence was 'as much a function of extensive disease at presentation as of preliminary tracheotomy'.

In another study (El Shennawy *et al*., 2000) statistical analysis was performed to determine the correlation between peristomal recurrence, and the site of the primary tumour, its stage, the presence of nodal metastases and the performance of an emergency tracheostomy more than 48 hours before surgery. Peristomal recurrence occurred in about 6% of laryngectomised patients. The authors concluded that there was a significant correlation between peristomal recurrence and the involvement of the subglottic area, T4 stage of the primary tumour and nodal metastases. They found no correlation between peristomal recurrence and emergency tracheostomy.

Narula *et al*. (1993) concluded that emergency laryngectomy offered patients no survival advantage. On the other hand, they maintain that emergency laryngectomy has some very definitive disadvantages. These include the necessity to rely on frozen section analysis, the difficulty in obtaining expert anaesthetic support, and the inability to provide thorough and complete nutritional and metabolic work up before major surgery. Finally, the psychological aspects of radical surgery for patient and family cannot be adequately addressed.

3. Restoration of airway with endoscopic laser assisted debulking

Malignancy of airways can affect both upper and lower airway. There are subtle differences in endoscopic laser management to relieve obstruction at these sites.

3.1. Endoscopic laser-assisted debulking of the lower airways

The obstruction of the lower airways due to bronchogenic carcinoma is usually of insidious onset, and rarely presents itself as an acute, life threatening emergency. Bronchoscopic CO_2 laser coupler, which focuses the beam at a suitable distance within the trachea and the upper bronchi, has been available in clinical practice at the very outset. In addition, fibre-transmissible Nd:YAG laser could be used by chest physicians down the flexible bronchoscope. Laser debulking therefore became a routine management for lower airway obstruction as a palliative measure (Stephens *et al*., 2000; Santos *et al*., 2004). A fuller discussion of this topic is covered in Chapter 56. The following paragraphs deal *per se* with management of obstruction due to malignancy at laryngeal level.

3.2. Endoscopic laser-assisted debulking of the upper airways

Transoral endoscopic debulking for acute laryngeal obstruction has been described in only a handful of publications in the head and neck literature despite the familiarity of most head-and-neck surgeons with the use of the laser in the treatment of upper aerodigestive tract malignancy. Nevertheless, the authors suspect that it is more widely practised than the literature suggests. The negation of almost all the disadvantages of tracheostomy (Box 1) makes endoscopic laser debulking an attractive option where indicated. In addition, transoral debulking is also a feasible option in the preoperative and palliative management of patients presenting with advanced laryngeal disease.

4. Literature review

Despite the laser being used routinely for the treatment of both benign and malignant lesions, only a few studies have reported on the results of transoral debulking for the treatment of obstructive laryngeal

Table 1. Summary of results of the studies in the literature

Author(s)	*Year of publication*	*Number of patients*	*Number for palliation*	*Number of procedures*	*Technique*	*Success rate*
Vaughan (Vaughan 1978)	1978	6	0	6	CO_2	100%
Davis (Davis *et al.*, 1981)	1981	10	1	10	CO_2	90%
McGuirt (McGuirt *et al.*, 1987)	1987	10	0	10	CO_2	100%
Shapshay (Shapshay *et al.*, 1988)	1988	7	0	7	CO_2	100%
Leontsinis (Leontsinis *et al.*, 1996)	1996	2	0	2	CO_2	100%
Laccourreye (Laccourreye *et al.*, 1999)	1999	50	8	66	CO_2	92.8%
Simoni (Simoni *et al.*, 2003)	2003	27	3	29	MD	96%
Paleri (Paleri *et al.*, 2005)	2005	43	14	56	CO_2	91%
Phelan (Phelan *et al.*, 2007)	2007	4	0	4	MD	100%

tumours (Table 1). This is possibly due to the fact that only a limited number of patients require this procedure and that it can take several years to accumulate a significant series of patients. All studies use peri-operative mortality and avoidance of tracheostomy as the primary outcome measures. The procedure is considered successful if the patient is extubated and went on to have a definitive treatment plan without the need for a tracheostomy.

Only two large studies exist. The prospective study by Paleri *et al.* (Paleri *et al.*, 2005), from England, reports the technique and outcome of laser debulking performed on 43 patients. Laccourreye *et al.* (Laccourreye *et al.*, 1999), from France, published a retrospective study of 50 patients who were treated at a centre in France. Both these studies with relatively larger cohorts consisted of two groups of patients: those who underwent the procedure whilst waiting for curative treatment and those receiving palliative care and chose to avoid a tracheostomy.

Other surgeons have described the technique in smaller cohorts (Davis *et al.*, 1981; McGuirt *et al.*, 1987; Robson *et al.*, 1994; Leontsinis *et al.*, 1996; Rudert *et al.*, 1999). All the studies recruited similar groups of patients, who presented with symptoms of a compromised laryngeal airway and stridor.

4.1. Repetitive debulking

Some patients may require further debulking and the incidence is highest in the first six weeks after the initial debulking in patients receiving curative or palliative treatment. Paleri *et al.* (2005) reported successful restoration following re-treatment in all their patients, without conversion to tracheostomy. Periodic repetitive debulking may also be required in palliative patients as and when progression of the disease results in recurrence of obstruction. In one study 23 procedures were performed among the 14 palliative care patients (Paleri *et al.*, 2005). Smaller studies echo these findings with high rates of avoidance of tracheostomy. The perioperative mortality is reassuringly low with proper case selection, ranging from 0-4%.

5. Laser debulking of laryngeal obstruction

Laser debulking as an alternative to tracheostomy cannot be undertaken without considerable planning, preparation, and an availability of an experienced surgical, anaesthetic and nursing team. It cannot be overemphasised that these patients are in imminent danger of losing their life should laser debulking fail to restore *and* maintain life supporting airway. This is not a procedure for a novice, nor is it for an experienced surgeon *without* the support team, as it so commonly happens in the middle of night. The following paragraphs set out the authors' set up as a guidelines, which should be adopted to suit individual centres as necessary.

6. General considerations

Centres that perform such emergency surgery usually have a well-rehearsed routine to set the theatre up rapidly for the procedure when required. The middle of the night should *not* be the first time to set the theatre up for laser debulking. It must be recognised that most centres will have only a limited cohort of theatre nurses accredited to use the laser. It is also likely that not all anaesthetists will have the necessary expertise to undertake the procedure. In addition, a careful postoperative monitoring is necessary, with a dedicated interventionist should the need arise. Thus, debulking airway surgery, especially with the laser, is best performed when adequately trained and experienced personnel are present. It is essential to have tracheostomy tray and supplies instantly available and in readiness, in the immediate vicinity, should planned debulking be aborted for whatever reason.

7. Instrumentation

7.1. Microlaryngeal instruments

Microlaryngeal instruments needed for the procedure include grasping forceps larger than those used for conventional microlaryngeal work. These instruments should have a matt or ebonised finish to minimise reflections on the surgical field that can cause excessive tissue damage or airway complications.

7.2. The suction cannulae

The suction cannulae need to be longer than the usual ones for diagnostic laryngoscopy, they should be 22 cm long so that subglottis and trachea can be reached.

7.3. A monopolar diathermy

Access to monopolar diathermy is necessary to control bleeding. The authors recommend both suction diathermy cannula and laryngeal monopolar diathermy forceps with integrated suction.

7.4. Tracheo-bronchoscope

A tracheo-bronchoscope is necessary to inspect and undertake bronchial toilet.

8. The laser

While the authors recognise that the procedure can be carried out using the KTP, diode and the Nd:YAG lasers, we prefer to use the CO_2 laser, which can be delivered to the operating site without the carrier handle, as non-intrusive, ‘handle-less’ free beam, providing an unobstructed, full view of the lesion.

8.1. Laser set up – nursing and laser technicians’ roles

The laser operator should perform a methodical check of all electrical components prior to activation of the laser system. The laser operator is also responsible for maintaining the safety of all theatre personnel including the issue and the use of appropriate laser safety equipment. He or she ensures that the theatre remains a safe area at all times. The operating microscope, laser unit, micromanipulator and dedicated smoke extractor are brought in and set up. The equipment is checked before bringing the patient to theatre to ensure that there are no untoward problems with the set-up. Close dialogue with the surgeon is of paramount importance so that the theatre staff are forewarned of the treatment plan and are thus in readiness to deal with any potential complications.

The laser is test-fired on a wooden spatula placed on a wet drape, checking the alignment of the He-Ne beam to the CO_2 beam. A tracheostomy tray is set up *prior* to induction and remains assembled until an airway is established and the patient safely extubated. The operating surgeon should have already expressed a preference for the appropriate laryngoscope/bronchoscope although a variety of scopes should be readily available.

9. Patient selection and indications

A correct patient selection will ensure a successful outcome. None of the case series on tumour debulking (see below) report an initial conversion rate to tracheostomy or failed intubation rate. This implies that laser debulking was an appropriate option for these patients.

Proliferative lesions of the glottis and supraglottis are very well suited for a debulking procedure (Figure 1A-C).

Isolated subglottic lesions, such as those caused by direct infiltration of thyroid tumours or primary subglottic malignancy, can also be successfully dealt with by this technique.

In contrast, patients with more infiltrative tumours, where the bulk of the tumour is submucosal and extends in to the paraglottic space, are poor candidates.

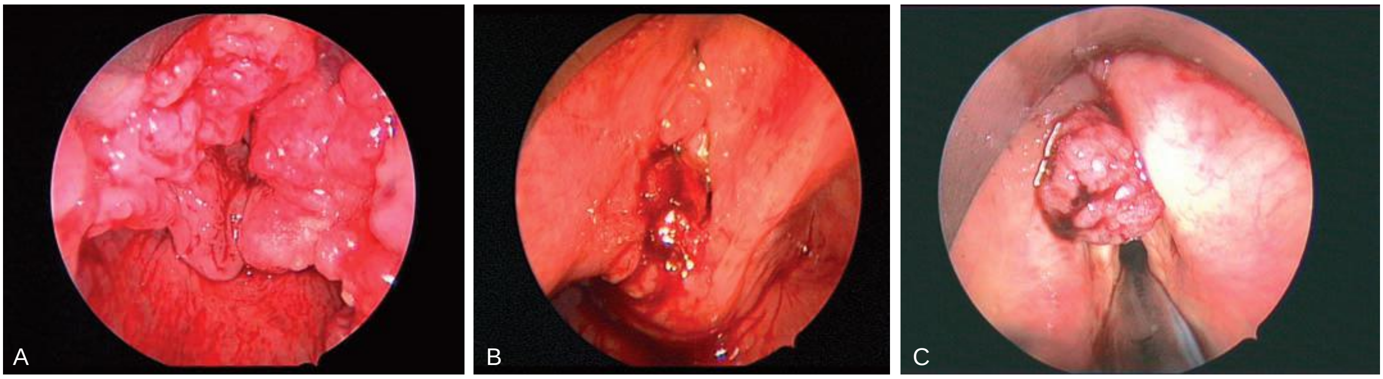

Fig. 1A-C. Examples of proliferative obstructive laryngeal neoplasms, suitable for the laser debulking procedure.

In scenarios where the airway compromise is caused by transglottic or hypopharyngeal cancers, there is extensive infiltration of the paraglottic space and contraindicates debulking.

The authors also recommend use of the procedure for patients who present with a large, proliferative lesion, but do not have any clinical evidence of a compromised airway. Prophylactic debulking will reduce the chance of a compromised airway in the near future as the patient is being planned for or receiving non-surgical treatment.

Poor pre-existing lung function will contra-indicate the procedure, even if the tumour is deemed to be suitable for laser debulking.

10. Clinical evaluation of the compromised airway

This is best performed by the surgeon intending to undertake debulking, and ideally by an experienced head-and-neck surgeon. As in other causes of airway compromise, the status can change rapidly, and the initial assessment will provide a baseline impression of the extent of decompensation.

10.1. Airway obstruction

Depending on the presentation, a comprehensive history may or may not be feasible. One should at least confirm the presence or absence of a pre-existing hoarse voice, dysphagia, symptoms suggestive of aspiration and a history of gradual worsening of the airway over a period of days rather than hours (which may indicate, but not invariably, an infective rather than a neoplastic process).

10.2. Co-morbidity

Nearly 60% of patients with head-and-neck cancer have concurrent medical disease (co-morbidity) at presentation, one of the highest figures seen in any tumour site (Paleri *et al.*, 2010). Particular attention should be paid to current medications, since this is likely to influence treatment choice of the obstructed airway.

10.3. Clinical examination

Clinical examination should include an assessment of the extent of hypoxia and the work of breathing (Box 2). It is possible to comprehensively assess the larynx using a flexible nasolaryngoscope, unless the patient is *in extremis*. This is preferably done in a scenario where facilities are available to rapidly stabilise the airway in the rare event of laryngeal spasm. The authors prefer no local anaesthesia for the following reasons: the local anaesthetic spray leads to coughing spasms and the resultant numbness of the throat causes more anxiety as the patient is unable to feel the normal airflow through the pharyngolarynx during respiration. By generously lubricating the tip of the flexible telescope and by careful attention to technique, the examination can be accomplished with minimal discomfort in the majority of cases. Endoscopic assessment should include the site and size of the neoplasm, the extent of airway compromise and distortion of the normal anatomy, which must be graphically communicated to the anaesthetic colleagues. The latter findings are especially important, as the anaesthetists place significant reliance on normal landmarks to secure the airway. Where facilities are available, the nasolaryngoscopic image should be captured to facilitate discussion of the management strategy with the rest of the team.

Box 2. Clinical evaluation

- Respiratory rate
- Cyanosis
- Apnoeic spells
- Use of accessory muscles
- Intercostal / sternal / subcostal recession
- Nasal flaring
- Timing / severity of stridor
- Hoarseness

11. Anaesthetic considerations

At best of the times, the anaesthetic and surgical priorities in laryngeal laser surgery are diagonally opposite. The anaesthetist needs to secure and maintain adequate controlled ventilation, in the very location where surgical procedures are ever intruding. A compromise and a solid cooperation of the two specialists is the foundation stone for a successful laryngeal laser surgery.

The anaesthetic consideration for debulking acute laryngeal obstruction makes for one of the most complex clinical scenarios in anaesthetic setting. The successful management of these cases requires a balance between adequate airway control and appropriate visualisation of the laryngeal pathology requiring debulking.

The American Society of Anesthesiologists (ASA) guidance emphasises the use of airway algorithms to help the best airway management, *i.e.*, if plan A is intubation, a reserve strategy for failed intubation (plan B) must be in place (2003). Fibre-optic intubation in the patient with an anatomically difficult and partially obstructed airway due to laryngeal cancer is *ill advised*, and can result in complete airway obstruction and fatal complications. A gas induction followed by careful laryngoscopy and intubation to secure the airway prior to administration of neuromuscular blocking drugs is more appropriate (Mason *et al.*, 1999).

11.1. Co-morbidity

The typical patient requiring laser treatment may be regarded as medically 'high-risk' male, in his seventh decade, often with serious cardio-respiratory co-morbidity perhaps secondary to lifelong tobacco and alcohol abuse (Paleri *et al.*, 2010). The anaesthetic review must concentrate on appraising the patients' general health. Assessment and treatment of co-existing conditions should be performed as per local or national guidelines.

11.2. Airway evaluation

Airway evaluation should include: examination of previous anaesthetics notes for difficulties, an assessment of mouth opening, tongue protrusion, thyromental distance, and range of neck movement. The findings on flexible nasolaryngoscopy, chest X-ray and cross-sectional imaging (usually computed tomography), where available, will provide information on the laryngeal inlet, presence of tracheal deviation, and any subglottic extension which will help determine the best airway strategy (Pearce, 2008). Signs and symptoms of shortness of breath, and the degree of stridor will help determine the severity of airway obstruction (Box 2) and therefore, a potential to difficult or even failed intubation. A certain degree of bleeding from the tumour due to intubation trauma and sequestration of tumour tissue is to be anticipated.

11.3. Airway fire

Airway fire is an ever-present risk irrespective of anaesthetic technique utilised. An airway fire drill should be in place and practiced by all staff involved in laser surgery. Use of inspired oxygen concentrations should be as low as practically possible (FiO_2 0.3-0.4) to maintain satisfactory oxygen saturations as appropriate, either as an oxygen/air or oxygen/helium mix (Van Der Spek *et al.*, 1988). Helium has the added advantages of reducing the work of breathing. Diathermy used to control bleeding is also a source of ignition particularly if oxygen is trapped under the drapes.

11.4. Patient safety

Patient safety includes moist pads for eye protection, wet drapes to cover the face and the use of moistened neuropatties to protect the cuff if a cuffed endotracheal tube is used. Patient monitoring during laser surgery consists of pulse oximetry, ECG, and non-invasive blood pressure measurements. Blood gas analysis may be required to assess respiration, particularly if jet or spontaneous ventilation methods are used.

12. Anaesthesia

There are three main techniques that can be used to ventilate patients during suspension laryngoscopy for laser surgery:

- Endotracheal intubation with mechanical ventilation;
- Spontaneous ventilation;
- Jet ventilation (Paes, 1987).

It is essential that the anaesthetist be familiar with a number of different ventilation techniques, as more than one approach may be required during a single case. The choice of airway access and ventilatory mode is determined by the type of laryngeal disease, patient parameters (cardiac/respiratory impairment), and extent of surgical access required.

12.1. Endotracheal intubation and mechanical ventilation

There are a number of cuffed flexi-metallic laser-safe endotracheal tubes on the market which can be used to provide airway control during surgery. The advantages include the anaesthetist's familiarity with the technique, airway security, prevention of airway soiling and peri-operative monitoring of ventilatory parameters. Disadvantages include limited surgical view and access to lesions located in the posterior commissure or subglottis (Patel, 2008; Juneja *et al.*, 2009). The larger diameter of these tubes may result in difficult passage through a glottis narrowed by tumour.

The endotracheal cuff is a potential fire hazard if ignited by the laser. It is inflated with tinted saline (*e.g.*, with methylene blue), so that any puncture of the cuff with consequent loss of integrity is immediately and visually confirmed. It also acts as heat sink for the laser energy.

If intubation is unsuccessful, a rigid tracheobronchoscope or the Negus intubating laryngoscope with the sliding panel can be used to assist with intubation.

12.2. Spontaneous respiration

For airway surgery, this is an ideal technique as it provides an optimal view of the whole larynx without the need for intubation. The technique relies on the ability of the anaesthetist to maintain an adequate level of ventilation. Oxygenation is maintained through insufflations via a pharyngeal catheter and anaesthesia can be maintained using a total intravenous technique (Paes, 1987). Topical local anaesthesia (4% lignocaine) is required to reduce cord movement and the laryngeal reflex secondary to insertion of the laryngoscope. The main disadvantages are lack of a secure airway, and inability to monitor ventilation (Juneja *et al.*, 2009).

12.3. Jet ventilation

Jet ventilation maintains oxygenation by intermittent high-pressure injection of oxygen, air or a mixture through a catheter or laryngoscope. This technique requires an intravenous method of anaesthesia to ensure unconsciousness. Ventilation may be delivered manually using a Sanders injector at low frequency or automatically, using a jet ventilator at low or high frequency. The method can be divided into supraglottic, subglottic and transtracheal techniques, all of which have been successfully used to facilitate laryngeal surgery.

Jet ventilation is difficult in patients with obesity or severe lung disease, and may be contraindicated in these situations. The risk of barotrauma is greatest with transtracheal, less with subglottic and least with supraglottic ventilation Barotrauma injury (subcutaneous emphysema, pneumomediastinum, pneumothorax, tension pneumothorax) to the tracheobronchial tree is a risk in all jet techniques especially in the setting of a potentially obstructing laryngeal tumour (Jaquet *et al.*, 2006). Measures that may reduce barotrauma include: constant clinical vigilance of chest movement and exhalation, familiarity with and frequent use of the technique, and use of a jet ventilator with an automatic pressure shutdown facility (Cook *et al.*, 2008).

12.3.1. Supraglottic jet ventilation

Supraglottic jet ventilation uses a Venturi needle attached to a suspension laryngoscope to deliver high-pressure gas to the lungs. Alignment of the laryngoscope by the surgeon with the laryngeal inlet ensures efficient ventilation. Advantages include an optimal view and access to the larynx without a potentially flammable endotracheal tube (Patel, 2008; Juneja *et al.*, 2009). Cord movement and contamination of the lungs with smoke and debris can be reduced by pausing jet ventilation and by using a smoke extractor during laser strikes. Disadvantages include inability to monitor airway patency, airway pressure and end tidal CO_2 levels for ventilatory sufficiency. Displacement or poor alignment of the needle increases the risks of inadequate ventilation, barotrauma, or gastric distension.

12.3.2. Subglottic jet ventilation

Subglottic jet ventilation involves placing a specially designed laser safe catheter (Hunsaker Monjet, Jockjet tubes) through the glottis into the trachea. The small diameter (2-4 mm) of the catheters allows excellent visualisation of the larynx. Cord movement is minimal and debris is blown away from the lungs during jetting. Ventilation is more efficient than supraglottic ventilation and adequacy of ventilation can be ensured by the ability to monitor tracheal pressure and end-tidal CO_2 levels (Hunsaker, 1994).

12.3.3. Transtracheal jet ventilation

Transtracheal jet ventilation requires placement of a Teflon coated Ravussin catheter through the cricothyroid membrane. Advantages include an unobstructed view of the larynx, minimal cord movement and reduced risk of contamination of the trachea by laser debris. Tracheal pressure monitoring and end-tidal CO_2 levels can be measured to ensure adequate ventilation and reduce potential barotrauma injury. Disadvantages include failure to ventilate due to misplacement, or kinking of the catheter and tracheal haemorrhage at insertion (Ferguson *et al.*, 2008). There is also a possibility of tube ignition due to direct strike or flying hot debris or hot smoke.

13. Operative technique

The authors recommend that a choice of endoscopes be available to perform the debulking procedure. In our experience, the Lindholm or Rhys-Evans laryngoscopes are adequate for the purpose in the vast majority of cases. The former is useful for supraglottic and glottic lesions, whereas the latter can be used for glottic and even for subglottic tumours. Appropriate chest support, attached to the scope, rests on a Mayo stand secured to the operating table. A third-hand technique is used where necessary by strapping the larynx with adhesive tape to apply gentle pressure over the laryngeal framework. It improves access to the anterior aspects of the larynx and also steadies it during head movements to align target for direct *perpendicular* strikes which are most effective for rapid tissue ablation.

The patient is placed in a supine position, with the surgeon and the operating microscope at the patient's head end and the scrub nurse standing next to the surgeon. The anaesthetist and the anaesthetic machine are near the foot end of the operating table.

The debulking starts within the lumen and continued laterally until it is deemed that the airway is adequate. Aspiration of debris and blood commonly

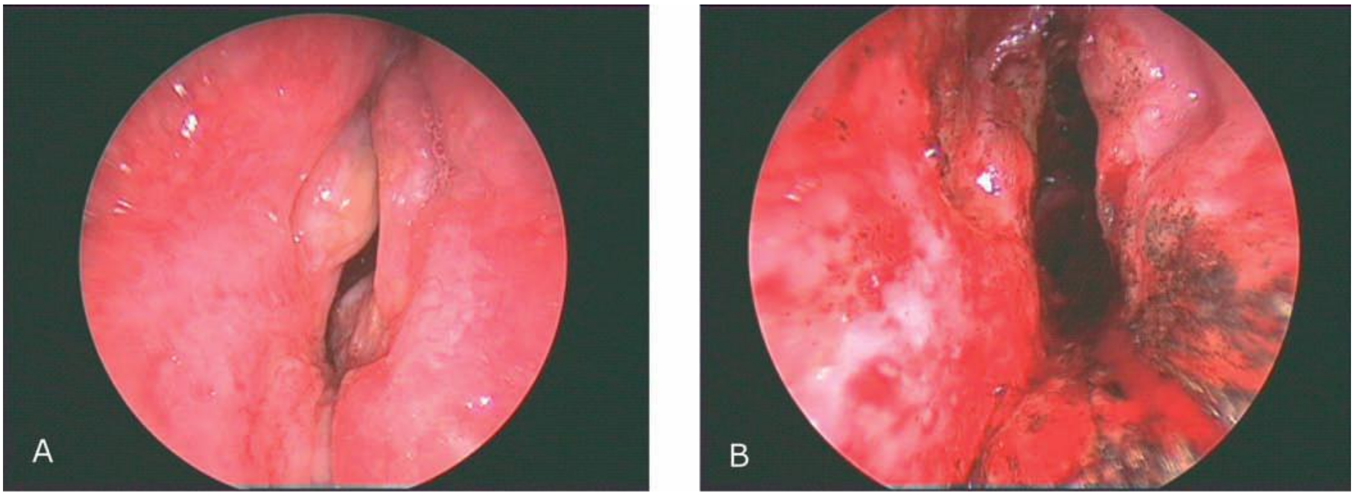

Fig 2. (A) Preoperative view of obstructing laryngeal malignancy (B) Postoperative view after debulking.

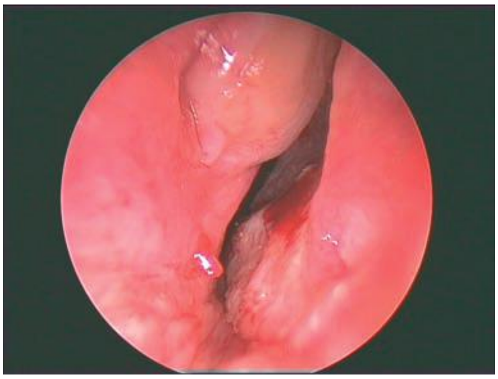

Fig. 3A. Transglottic neoplasm causing airway compromise.

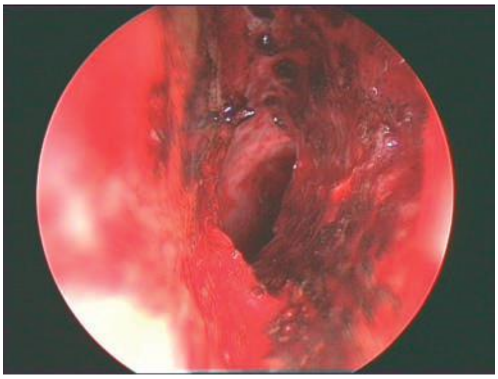

Fig. 3B. View following laser debulking showing dramatic improvement in the airway.

occurs following debulking procedures. If the procedure is done with any of the tubeless anaesthetic techniques, we recommend that tracheobronchoscopy be performed at the end of the procedure to clear out the debris in the lower airways.

13.1. Laser debulking

The technique was first described in the 1970's when Vaughn *et al*. used the CO_2 laser to provide a safe airway whilst allowing time for diagnosis and staging of obstructive laryngeal tumours without the need for a tracheostomy (Vaughan *et al*., 1978). Since the CO_2 laser has poor haemostatic properties compared to other types of lasers, a monopolar suction diathermy should be at hand. We prefer to leave control of the diathermy foot pedal to the scrub nurse, freeing the surgeon to focus on the laser foot control alone. Small neuropatties soaked in vasoconstrictor solution should be prepared to control oozing and protect the normal tissue from burning. If the microspot is used, the procedure is carried out using 10-20 W power in a continuous mode. If the Acuspot ™ is used, a wide diameter spot is used at 10 W.

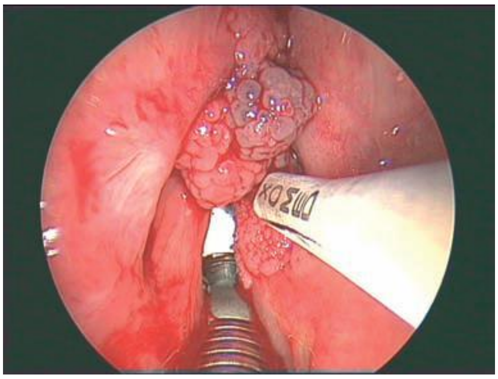

Fig. 4. The laryngeal shaver blade is used to debulk a papillary squamous cell carcinoma.

Once adequate tumour has been sampled for histological analysis, the debulking is commenced. The laser is used in a defocused mode. This will avoid cutting through the tumour and minimise bleeding. The tumour surface is charred and then the char cleaned with the sucker. The surface is now ready to be vaporised again and repetition of the process leads to a gradual volumetric reduction in tumour.

14. Microdebrider/shaver debulking

A more recent alternative to the laser, but based on similar principles, is the use of the microdebrider to perform debulking.

Proponents of this technique suggest that it can give better access to the anterior commissure and subglottis (Simoni *et al*., 2003; Phelan *et al*., 2007). At centres where access to laser is not possible outside normal working hours, the microdebrider is a useful alternative as it requires just the surgeon to be familiar with set up and usage and may be more advantageous in some settings. Specific shaver blades for use in the larynx are available that integrate with existing systems for use in sinonasal surgery.

15. Postoperative care

The benefits of debulking are apparent as soon as the procedure is complete. Stridor is less prominent, and many of the hypoxia related symptoms will have settled down. In the postoperative period, the patient is best nursed in the sitting position to aid lymphatic drainage and reduce any oedema of the oropharyngeal tissues, which may occur following suspension laryngoscopy. Steroids and nebulised racemic epinephrine may be helpful in minimising laryngeal oedema and humidified oxygen will reduce drying of oropharyngeal secretions resulting from use of jet ventilation. Chest physiotherapy is started as soon as feasible. We do not advocate the routine use of nasogastric tubes. This is not necessary for most of the indications mentioned above and needs to be decided on a case by case basis. A swallowing assessment is performed as soon as possible before the patient resumes oral intake.

16. Conclusion

Transoral laser debulking of obstructive laryngeal tumours represents an effective holding strategy in the treatment of critical or impending airway obstruction in a selected sub group of head and neck cancer patients. It has a high rate of success in avoiding tracheostomy, it allows a variety of definitive treatment options and is repeatable with no cumulative limits. However, significant team expertise is needed for patient selection and to safely perform the procedure.

It plays an important part in palliation and the maintenance of quality of life in incurable patients. It carries a low risk of complications and should be considered early in patients with airway compromise. The morbidity and mortality related to the procedure itself is low. Functionally, patients appear to do well, maintaining a safe swallow, although formal data about this is lacking.

16.1. Key points to successful debulking

- Ensure good communication among all teams involved in care
- Discuss a preoperative plan based on findings
- Use an anaesthetic technique that the team is familiar with
- Be aware that ventilation needs and techniques may change as the operation proceeds
- Pay attention to concurrent comorbidities.

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MCQ – 17. Transoral endoscopic management of acute obstruction caused by laryngeal malignancy

1. For acute malignant laryngeal obstruction, emergency tracheostomy
    a. Offers immediate relief for obstructed airway
    b. Requires highly skilled personnel
    c. Requires highly skilled anaesthetist
    d. Requires intensive care unit
    e. Requires specialised immediate postoperative care

2. Incidence of peristomal disease
    a. Is high in cases where emergency tracheostomy is performed
    b. Is related to the stage of the disease, and presence of metastasis
    c. Is more common if the stomal skin is included in the incision line
    d. All of the above

3. Emergency laryngectomy rather than emergency tracheostomy is preferable because
    a. It minimises risk of stomal disease
    b. It has a high probability of acceptance
    c. It reduces overall metabolic burden if radiotherapy is required for metastases
    d. All of the above
    e. None of the above

4. Emergency transoral debulking in preference to emergency tracheostomy is not widely practiced because
    a. It requires high-end equipment
    b. It requires a dedicated team
    c. Most tumours involve paraglottic region at presentation
    d. It is associated with significant perioperative mortality
    e. Periodic debulking is still required in a significant number of palliative cases

5. Emergency transoral debulking is suitable for
    a. Infiltrative as well as exophytic tumours
    b. Only for exophytic lesions
    c. Only for infiltrative lesions
    d. Patients with significant comorbidity
    e. Palliation of advanced laryngeal malignancy

6. Safe and therefore preferred method of anaesthesia is
    a. Induction by gas inhalation, followed by intubation
    b. Fibre optic intubation
    c. Neuromuscular blocking agents and intubation
    d. As per the expertise of the anaesthetist available for the emergency cover
    e. All of the above

7. Laser debulking can be undertaken with all of the following lasers except
    a. The CO_2 laser
    b. The CO_2 laser with a hollow waveguide
    c. The KTP laser
    d. The diode laser
    e. Pulse dye laser

8. Laser debulking requires
    a. No special instrumentation
    b. Large grasping microforceps
    c. Laser as well as microdebrider
    d. Monopolar diathermy
    e. Suction cannula longer than normal laryngeal suction cannula

9. Successful surgical outcome for debulking is achieved
    a. When the need for tracheostomy has been circumvented
    b. Only when further debulking is not required
    c. When further periodic debulking is not required
    d. When swallowing function is restored without aspiration
    e. When the patient does not require specialised nursing care

Chapter 18

Paediatric laryngo-tracheal airway

G.P.S. Siou and L. Daniels

1. Introduction

Like many parents with young children, we are constantly reminded that as boisterous as our little ones can be, they are still in many ways fragile and vulnerable. This point is underscored particularly when we are called upon to deal with a compromised airway.

The paediatric airway can present the clinician with a whole multitude of pathologies. Laryngomalacia, subglottic stenosis, webs and cysts are but a few examples (Table 1).

This chapter deals with setting up of a dedicated paediatric airway service, encompassing anaesthesia, instrumentation, an assessment, and the management strategy of the airway, specific to paediatric population.

There is no doubt that we would not be where we are today without the inspirational works of the Iranian physicist Ali Javan who introduced the science of Helium Neon, and electrical engineer Kumar Patel from India, who invented the CO_2 laser. The transition to clinical practice in the late 70's and early 80's heralded the beginning of a long association between lasers and otolaryngology (Maiman, 1965; 1966). Laser surgery in paediatric otolaryngology has found a niche within the realms of the paediatric airway. A considerable advantage is clearly seen when one considers the small workspace presented to the surgeon. Good tubeless total intravenous anaesthesia (TIVA), and the use of the microscope and CO_2 laser means that the surgeon only needs to have a suction cannula or forceps within the airway while operating. Add to this the inherent properties

Table 1. Paediatric airway pathologies

Supraglottis	Glottis	Subglottis	Trachea/Bronchi
Laryngomalacia	Laryngeal web	Subglottic stenosis	Tracheomalacia/bronchomalacia
Saccular cysts	Vocal cord paralysis	Haemangioma	Tracheo-oesophageal fistula
Laryngocoele	Laryngeal atresia	Laryngeal cleft	Agenesis
Lymphangioma	Cris-du-Chat syndrome	Laryngotracheo-oesophageal cleft	Vascular compression
Bifid Epiglottis			Anomalous bifurcation 'pig bronchus'
			Congenital cysts/tumours

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of the laser beam itself (bloodless surgery, co-axial delivery, no carrier handle, sealing of wound, etc.), it is small wonder that laser laryngeal surgery within the paediatric airway has become a popular modality in managing many pathologies.

It is appreciated that the target audience for this current text will be worldwide and varied in expertise and facilities available. A discussion around paediatric airway support in developing countries will be covered.

2. Paediatric airway service

Delivering a paediatric airway service is a multidisciplinary undertaking. There needs to be a close symbiotic collaboration between the paediatric otolaryngologist, the anaesthetist, a paediatrician and staff of paediatric ICU, The operating department staff needs to be conversant with the paediatric instrumentation. The airway assessment and laser techniques used in the paediatric setting are not too dissimilar to those in adults, but there are some significant differences that will be discussed.

2.1. Airway management where structured set up does not exist

This chapter has been written with a focus on a well-established paediatric airway set-up, or, where such development may be anticipated. This form of high-tech medicine, however desirable, is not cheap. It is appreciated that many readers will lack the high levels of support described here, by way of personnel, equipment or indeed, training.

2.2. Location

The child with airway problems may present with co-morbidity, and, although the first port of call is usually the respiratory paediatrician or an ENT surgeon, it may be necessary to call upon other specialties. A dedicated paediatric intensive care unit together with on site paediatric respiratory physician is mandatory in any paediatric service set-up. Given choice in a large metropolis, a hospital site that is also represented by, for example, cardiothoracic, plastic, paediatric and maxillo-facial surgical disciplines may be even more attractive for hosting an airway service. There must be appropriate in-patient and out-patient capacity, support and facilities installed in order to cater for a variety of caseload.

2.3. Personnel

Every paediatric airway service should have at minimum two dedicated ENT surgeons, paediatric respiratory physicians, paediatric anaesthetists, specialist nurses, speech and language therapist and dietician. The ENT surgeon should already be experienced in the emergency management of the paediatric airway. However, it is the authors' opinion that if undertaking such a regular role, then it is advisable to attend a validated Advance Paediatric Life Support Course and to ensure that they re-validate every three years (http://www.alsg.org/en). One will find that their anaesthetic and respiratory colleagues are already doing this and have done so for some time. The calibre of staff within outpatients and theatre must be considered. In outpatients, a multidisciplinary approach should be practiced. Combined airway clinics should be the gold standard for the assessment and management of all paediatric airway cases and has been shown to optimise the care delivered (Wiatrak *et al*,. 1997). These clinics should be structured so as to ensure that both ENT surgeon and respiratory consultant are present. This will ensure that appropriate patients are listed for the airway operating list, while others less urgent cases can be observed on a 'watch and wait' policy. In theatre, nursing staff must be appropriately trained in the management of acute airway cases and be fully conversant with all specialised instruments and equipment including safe operating of the CO_2 laser. In conjunction with this latter point, it is recommended that staff with direct involvement with CO_2 laser procedures attend an approved laser course (http://clevelandlasercourse.inous.co.in/LaserCourse.aspx). Such courses provide a comprehensive program with hands-on demonstrations and live surgery. Surgeons, anaesthetists and theatre nurses have all benefited in the past from such courses and have come away with important practical points to apply in their own centres. One must never forget the importance of the input and support from secretarial staff. Often the coordination of patient lists and ensuring the availability of a named surgeon and respiratory physician are critical to the smooth running of the service. It is paramount to ensure that a specific member of the respiratory department's secretarial staff has appropriate time set in their job plan to fulfil such a role. Equally, it goes without saying that job planning is also important for the ENT surgeon who already has a busy week with regular clinics and general ENT theatre sessions.

2.4. *Considerations for the pre-operative work up*

Once up and running, the multidisciplinary paediatric airway clinic can be a most fruitful and economical experience. With both the respiratory physician and surgeon present, many patients can be seen and immediate decisions can be made between adopting conservative or surgical management. If run solo, this would normally entail the paediatrician having to liaise with the surgeon perhaps the following day, and then organising another appointment for the parents and child to re-attend clinic, sometimes at a different hospital site. In tertiary referral centres often these families are travelling longer distances and although the chronicity and/or severity of their child's condition warrants this journey, it is nevertheless prudent to take this into consideration and to try and limit any unnecessary stress and inconvenience.

When a decision is made to list a child, the routine planning for pre-operative assessment should already be in place, but again having both a medical and surgical perspective can ensure that all eventualities are covered. Complex cardiopulmonary problems will likely need the input of paediatric cardiologists and cardiothoracic surgeons not to mention the assessment made by your dedicated paediatric anaesthetist. Subsequent necessary investigations can then be requested. The good links with local services as mentioned earlier can pay dividends as demonstrated by the child who may be in foster care or on a child at risk register, and consent is required for an important airway assessment.

3. Paediatric airway operating list

All paediatric airway lists must have both a consultant ENT surgeon and consultant paediatric respiratory physician present. Once a paediatric airway list has been organised, it is wise to ensure that all staff involved have been sent a copy of the list a day or two in advance. This gives all involved an idea of the cases to be performed, but perhaps more importantly reminds both the ENT surgeon and physician that they do have a list on that particular day. I have found this invaluable in the past, since after all we are all mortal and can at times forget! On the day of surgery there are a number of steps that must always be fulfilled to ensure the safe running of a list and the avoidance of any catastrophes.

3.1. *Pre-operative ward round*

This is an integral part of any planned surgical list. The benefit of taking the opportunity to speak to parents about their child's procedure cannot be overemphasised. In the case of the paediatric airway this is even more significant as often the majority of the list consists of cases requiring airway assessments and so often no definite plan can be predicted. However, after some experience one can develop the ability to recognise those cases that for example sound like laryngomalacia, especially if the associated history strongly suggests this. Consequently, one is then able to discuss the possibility of laser surgery and immediate post-operative care in PICU. Another benefit is that at times symptoms show dramatic improvement by the time children present to the elective list. In such cases it does present the team with the dilemma of whether to administer an anaesthetic for an examination or not. Each case is different, but generally if no stridor is present then such an investigative procedure could be postponed and a review organised in outpatients.

3.2. *Theatre preparation*

No paediatric airway list can be safely run with a skeleton staff. There is no room for errors and one cannot cut corners. A typical airway list can be very changeable and a stable airway can quickly deteriorate. The theatre staff must be prepared and reactive to such changes. All members of the theatre team must be fully compliant with instruments and the workings of all equipment. As both an ENT surgeon and respiratory paediatrician will be in attendance, theatre staff should assume that both rigid and flexible endoscopy equipment will be required. The World Health Organisation has developed a checklist protocol for all theatres to implement before every operative list (Reuther, 2009). This ensures that all factors are in place from the correct patient details, to any possible concerns that the surgeon or anaesthetist may have. This is something that many surgeons have always done, but has been made more formal. For the airway list, this part of the pre-list check is most important in communicating to the theatre staff exactly what instruments will be required and whether the CO_2 laser is likely to be used. It also provides an ideal opportunity for surgeon and anaesthetist to discuss the best approach when dealing with the shared airway.

3.3. PICU availability

As mentioned earlier, paediatric intensive care provision is mandatory for any unit providing paediatric services (Fig. 1).

In view of the sometimes complex airway pathologies seen, availability of such a specialist resource is reassuring. However, it is important to show some foresight when electively listing patients. It is customary in our unit to admit all patients to PICU following endolaryngeal laser surgery. Of course, this is only possible if a bed is available. It is well within the control of the listing physician or surgeon to organise such support for the day, but once that day arrives little can be done if an emergency admitted the night before has taken up that bed. The message here is again good communication across all departments and an anticipation of potential post-operative complications.

Fig. 1. Paediatric intensive care unit.

4. Paediatric endoscopy

The ultimate aim of paediatric endoscopy is to achieve accurate diagnostic information in a safe and controlled manner. There are four requirements that will ensure this.

- Highly experienced nursing and medical staff;
- Specialised paediatric endoscopy equipment;
- A sound knowledge of paediatric airway anatomy and physiology;
- Good anaesthesia.

4.1. Theatre staff

Theatre nursing staff that perform regular paediatric airway lists must be trained to a high standard and are the integral part of a team to support the smooth running of any list. Apart from being familiar with the various instruments used, there is also the need for optimum staffing levels. In the author's view, it is a liability to operate such lists with an understaffed team. The reason for this is that there are too many pieces of equipment to be managed by two individuals (Fig. 2).

Ideally, there should really be no less than three nurses present with specific designated roles. A floor nurse, a scrub nurse, and a nurse operating the CO_2 laser. The floor nurse can often operate the video image recording stack as well as fetching additional equipment that may be required. A fourth nurse, however, would be much appreciated. If the floor nurse needs to leave theatre for any reason, the fourth nurse would then be free to operate the video stack as well as performing other additional duties until the floor nurse returns. One can see very quickly how matters can easily become frustrating if there were only two nurses to start with.

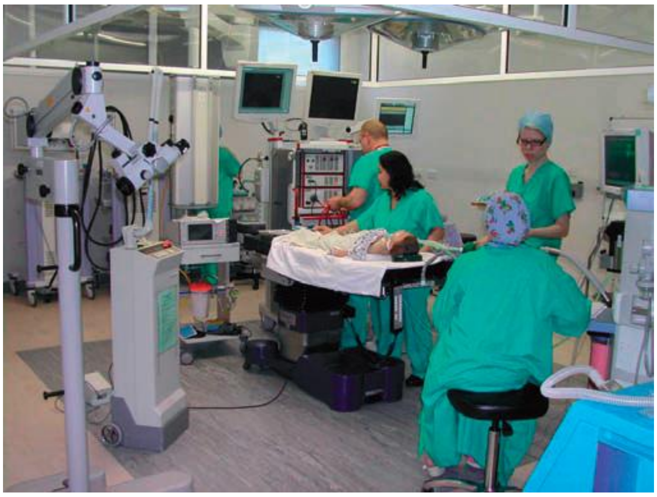


Fig. 2. Typical theatre set up.

4.2. Paediatric endoscopy equipment

The British Association for Paediatric Otorhinolaryngology minimum equipment standards for paediatric airway endoscopy is shown in Table 2.

There are a number of specialised paediatric endoscopy sets that are required for every airway list.

Table 2. Paediatric endoscopy equipment.

EQUIPMENT
Selection of age-appropriate paediatric laryngoscopes
Adjustable laryngeal suspension arm
Operating microscope with 400*f* lens
Microsurgical instruments (microscissors, probes, cupped and straight forceps)
Selection of age-appropriate ventilating bronchoscopes
Hopkins rod telescopes
Light source and fibreoptic cable
AV stack (camera, monitor, video and still capture, printer)
Optical forceps with graspers for removal of foreign bodies
Selection of flexible bronchoscopes
Paediatric tracheostomy surgical tray
Selection of paediatric tracheostomy tubes

It is crucial to have a set of Storz ventilating bronchoscopes to hand (Fig. 3).

These must be checked regularly and both nursing and medical staff must familiarise themselves with these instruments. The Hopkins rod telescope revolutionised the clarity with which the airway could be assessed. In emergency cases, it is possible to load these with an endotracheal tube and intubate the glottis under direct vision (Fig. 4). Basic paediatric laryngoscopes (Benjamin, etc.) or a simple intubating laryngoscope are essential when used in conjunction with the Hopkins rod to adequately expose the laryngeal area (Fig. 5). Although most lasering within the upper airway requires only a suction cannula, it is standard to have various forceps to hand as well optical graspers in cases of foreign body inhalation (Fig. 6).

4.3. *Paediatric airway anatomy and physiology*

Without stating the obvious, the anatomical paediatric airway is smaller than that of the adult. The

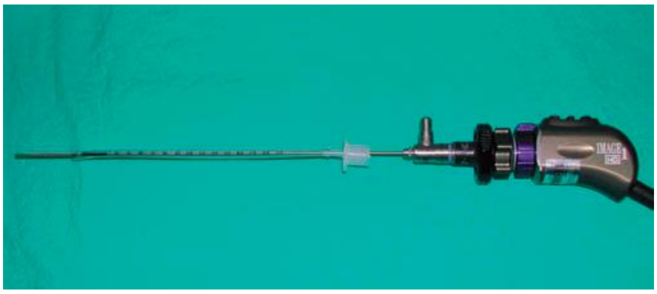


Fig. 4. ET tube, mounted on Hopkins rod.

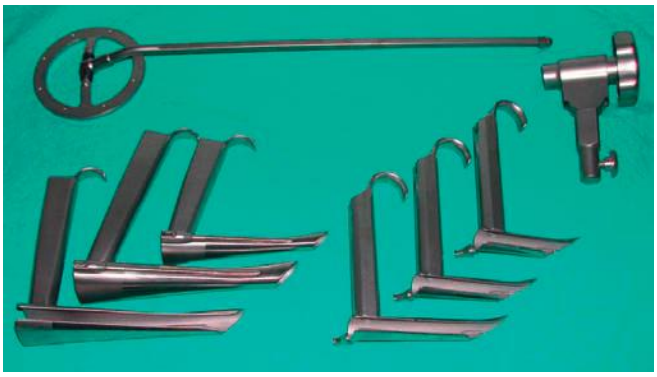


Fig. 5. A range of laryngoscopes.

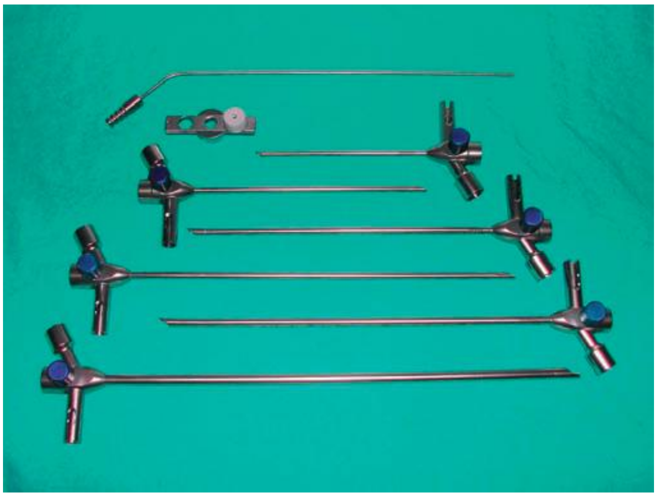


Fig. 3. Storz ventilating bronchoscopes.

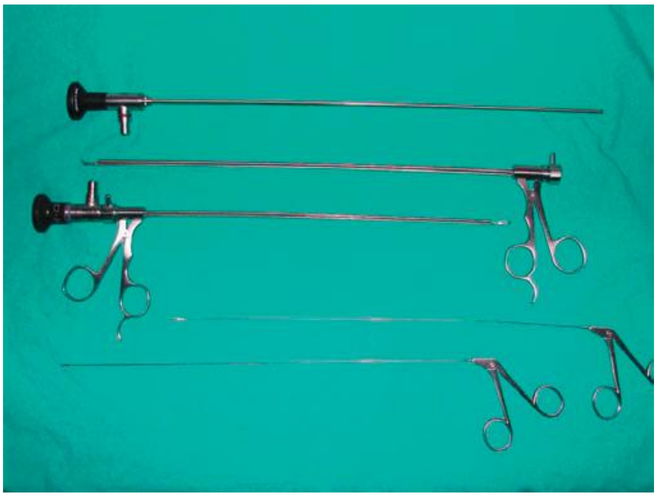


Fig. 6. A range of forceps and optical graspers.

larynx is much higher in the infant. The cricoid sits at the level of the C4 vertebra whereas the adult cricoid is at the C6 vertebra. The narrowest part of the adult airway is the glottis whereas in the infant the narrowest part is the immediate subglottis. This subglottic area corresponds to the cricoid, the only continuous ring of cartilage present within the airway. Any swelling of the respiratory mucosa in this area will have differing effects on the adult and child respectively. If you remember your physics from school, you may recall Poiseulle's law, which describes an inverse relationship between resistance to flow within a tubular structure and the radius of that structure to the fourth power. With this in mind, should an infant's subglottic mucosa swell by one mm, this will produce a 16-fold increase in airway resistance (Fig. 7A, B).

A similar increase in an adult would only produce a three-fold increase in resistance. This explains the rapid manner in which paediatric airway patients can suddenly decompensate with an almost totally obstructed airway. Decompensation is also made worse by the inherent higher metabolic rate of neonates that promotes a higher rate of oxygen consumption. Children cannot tolerate long periods of apnoea due to their smaller lung capacity.

5. Anaesthesia for paediatric endoscopy

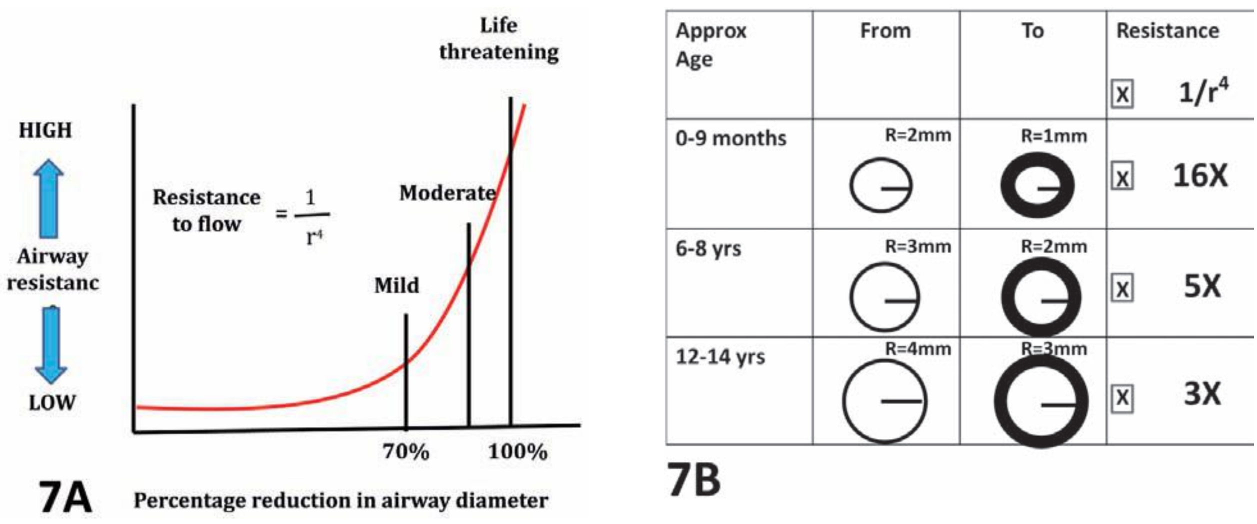
Anaesthesia for airway endoscopy and in particular laser surgery in children presents us with a unique challenge of a *shared airway*, and communication between anaesthetist and surgeon is essential for optimal outcome.

Experienced paediatric anaesthetists who regularly perform anaesthesia for airway endoscopy will use their individual skills and experience to tailor the choice of anaesthetic technique and method of airway management. Planning requires a clear understanding of the patient's medical condition, and the likely airway pathology. Close co-operation between the surgeon and anaesthetist is paramount to achieving surgical requirements, as an accurate diagnosis particularly of dynamic airway pathology may be very difficult. Abnormal airway anatomy or pathology can complicate access to the airway and it is essential to prepare for all eventualities including an emergency tracheostomy. This necessitates a full discussion with the child/parents so that they understand all potential outcomes.

For diagnostic laryngoscopy we ideally require an asleep, still, spontaneously breathing patient without laryngospasm so that careful assessment of cord and cricoarytenoid movement can be made. To enable an unobstructed view of the larynx the patient needs to be maintaining their airway without the security of an endotracheal tube. Hence the happy balance of depth of anaesthesia: too deep and they become apnoeic, and too light may precipitate coughing and laryngospasm.

These children should be starved as the risk of aspiration of stomach contents is greater in the presence of airway obstruction, where anaesthetic induction may be prolonged and difficult, making gastric distension more likely.

In general, sedative premedication should be avoided as many of these patients have some degree of airway obstruction. The use of anticholinergics is advocated by many in order to provide some



Approx Age	From	To	Resistance ☒ $1/r^4$
0-9 months	R=2mm	R=1mm	☒ 16X
6-8 yrs	R=3mm	R=2mm	☒ 5X
12-14 yrs	R=4mm	R=3mm	☒ 3X

Fig. 7 A. Poiseuilles graph; B. Poiseuilles diagram.

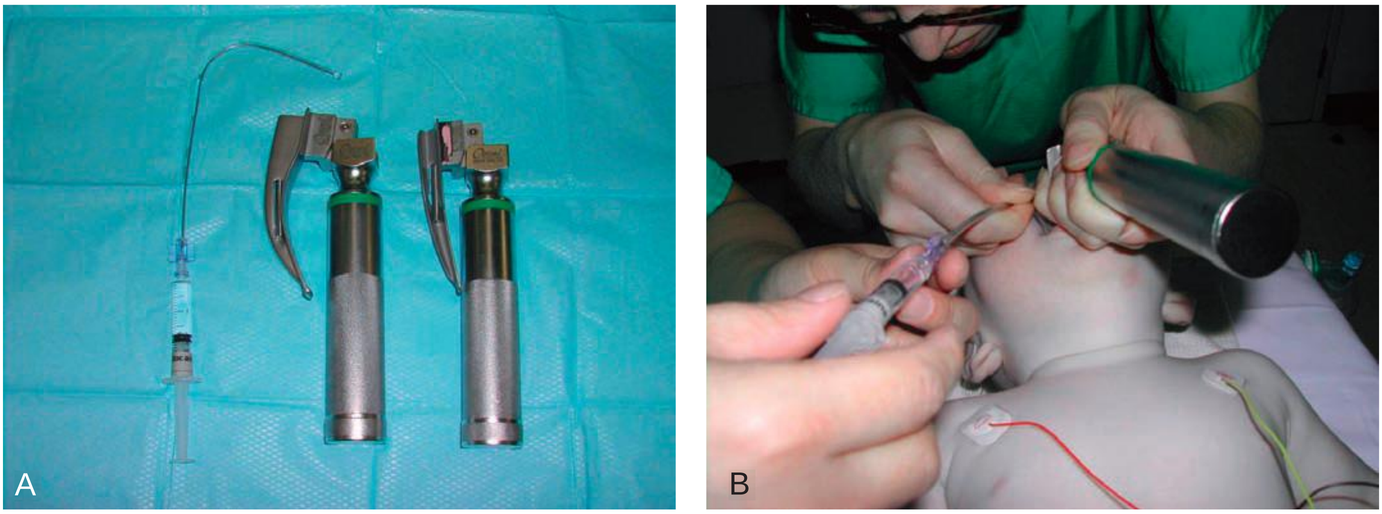


Fig 8 A. Mucosal Atomiser Device (MAD); B. MAD in use.

drying of secretions, thus allowing for more effective topical anaesthesia. They also help to prevent the bradycardic effect of inhalational anaesthesia (Mausser *et al*., 2007). Glycopyrrolate 10 mcg/kg or Atropine 20 mcg/kg are both commonly used to achieve this.

Anaesthetic technique is an individual preference. It is common practice in many centres to use a Total Intravenous Anaesthesia (TIVA) technique. The advantages are reduced theatre pollution by anaesthetic gases, and a titratable degree of hypnosis (Eyres *et al*., 1978). In authors' centre an inhalational induction is most commonly used, as described here. Anaesthesia is usually induced with a volatile agent (Sevoflurane) in 100% Oxygen, and then intravenous access immediately established. These children are maintained in 100% Oxygen and Sevoflurane breathing spontaneously via a facemask. Positive airways pressure (CPAP) may help to improve gas exchange. The stridor of laryngomalacia will often improve or disappear, whereas the fixed biphasic stridor of subglottic stenosis will not improve.

Good topical anaesthesia of the larynx with 1% lignocaine is the key to avoiding coughing, breath-holding and laryngospasm during endoscopy, especially during emergency, when the assessment of cord and cricoarytenoid function is made.

The most efficient method of delivering topical anaesthesia is via the Mucosal Atomiser Device (MAD), (Fig. 8A,B). Doses of lignocaine up to 4 mg/kg have been used in many large series without complications (Byers *et al*., 1978).

More dilute preparations may be necessary in the neonate.

5.1. Microlaryngoscopy

In order to achieve the best views, we maintain anaesthesia by insufflation. A soft, fine bore suction catheter is inserted as a nasal airway into the pharynx and the tip pulled back under direct vision using a laryngoscope to ensure that the tip does not project beyond the soft palate (Fig. 9A-C).

A small endo-tracheal tube could also be used instead of a suction catheter, but this may be quite cumbersome in a small neonate. The surgeon then has unrestricted access to the larynx which is essential in the neonates. Choosing a technique that requires intubating this group of patients would result in obstructed views, and restricted surgical access working around the tube, making surgery more difficult.

Once the suspension laryngoscope and microscope are in position, anaesthesia is maintained by insufflation of 100% oxygen and a volatile agent, either Sevoflurane or Halothane. Halothane is more potent than Sevoflurane, but its availability varies according to institution. If the depth of anaesthesia lightens a little whilst using the insufflation technique, small boluses of the intravenous anaesthetic agent, propofol may be administered. Close monitoring throughout the endoscopy is essential to detect hypoxia and hypoventilation, so that prompt action may be taken to avoid serious consequences (Werkhaven, 2004). A pulse oximeter whose pitch

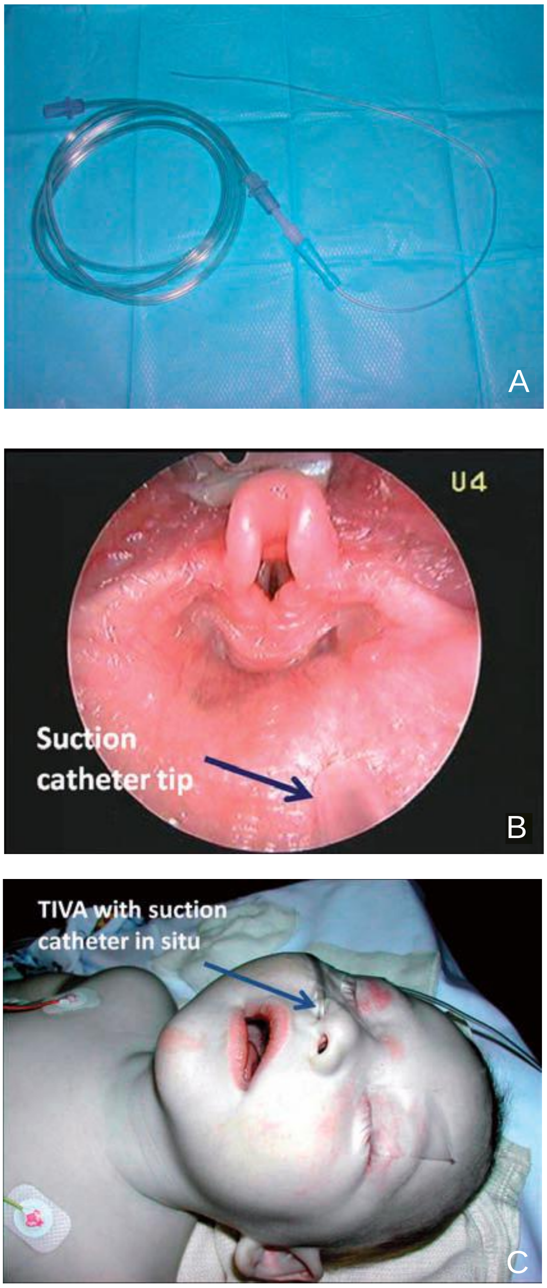


Fig. 9 A. Fine bore suction catheter.; B. Suction catheter tip prior to withdrawal behind soft palate; C. TIVA with suction catheter in place.

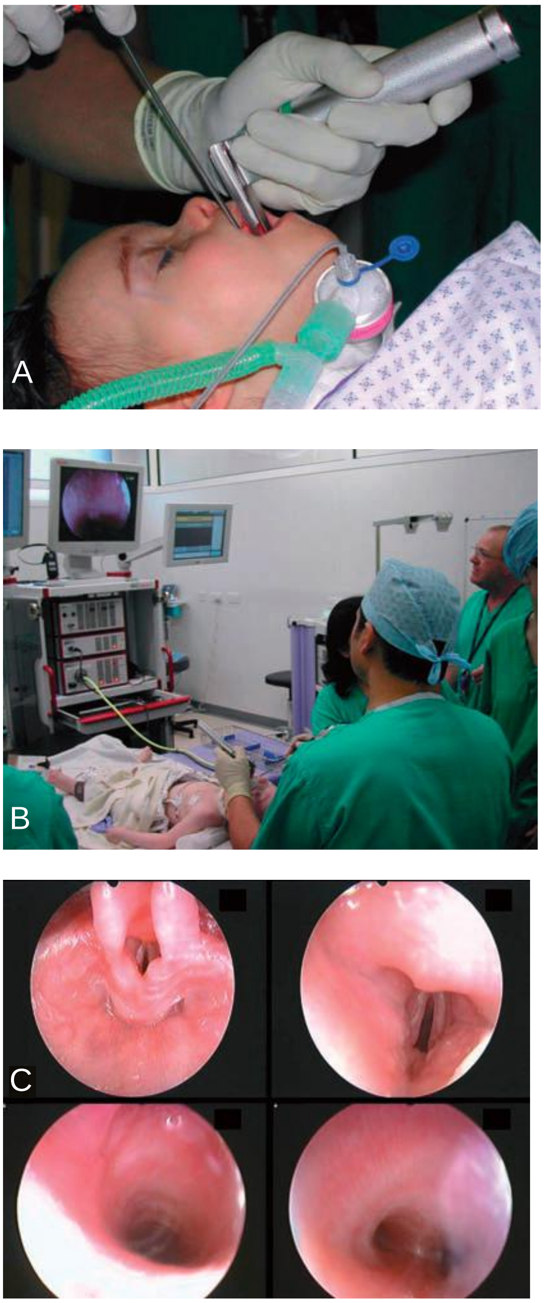


Fig. 10 A. Microlaryngobronchoscopy; B. Microlaryngobroncholsopy – monitoring; C. view of supraglottis, glottis, trachea and carina.

changes clearly as the oxygen saturation declines helps to alert the surgeon to the problem, and the possible need to interrupt the procedure. The use of a camera and video display allows the anaesthetist to see what is happening to the airway during the procedure (Fig 10A-C).

At the end of the procedure the inhalational agent is discontinued, the patient turned on their side, the nasal airway removed and the patient transferred to recovery breathing 100% oxygen. The patient should be monitored carefully until fully awake. Intravenous steroids (Dexamethasone 0.1-0.2 mg/kg) may be given if signs of airway obstruction worsen. Nebulised Adrenaline 1:1000 0.4 ml/kg up to a maximum of five mls may also be of benefit. This group of patients exhibiting signs of worsening airway obstruction immediately post operatively should be monitored in a high dependency setting as they occasionally need to be re-intubated. All patients who have received topical lignocaine to the larynx should remain nil by mouth until two hours post spray as a precaution against aspiration.

5.2. Anaesthesia for laser surgery

It has already been discussed that all those involved in the use of lasers for airway surgery must be aware of the hazards to both the patient and the operating theatre personnel. The patient is also at risk from inadvertent laser burns to normal tissues hence the patient's eyes and face must be covered with moist gauze swabs which will absorb stray laser energy. The greatest risk to the patient is that of an airway fire. These may arise from the ignition of non-metal materials, usually tracheal tubes. Both Oxygen and Nitrous Oxide support combustion. However, gas mixtures do not absorb laser energy and cannot be ignited. If the lasers beam strikes metal, it will be deflected and the energy scattered. All tracheal and tracheostomy tubes used should be metallic. Laser tubes are laser-resistant rather than laser proof and may still ignite if the laser power is high or if the tube is exposed to the laser beam for a prolonged period (Leong and Black, 2009). An example is the Laser-Flex tube® (Fig. 11), which has a larger OD for its ID as it has a thicker wall made of a flexible stainless steel hose to reflect the laser.

The choice of anaesthetic technique and method of airway management during laser treatment of the larynx depends on the child's age and size, pathology being treated and the preferences of both surgeon and anaesthetist (Best, 2009). In our centre we have a high neonate population. The smallest Laser-Flex® tube with a 3.0 mm internal diameter has an external diameter of 5.2 mm. This makes surgical access in our smaller patients very difficult, which is why our preferred method is to use a tubeless technique. The set up is as described previously for microlaryngoscopy with oxygen- enriched air and a volatile agent (Sevoflurane or Halothane) administered via a nasopharyngeal airway. The inspired Oxygen is reduced to a minimum level tolerated by the patient by using air in order to minimise the risks of combustion. Nitrous Oxide should not be used as it supports combustion. The patient's face and neck are draped in warm wet swabs. It is important to try and minimise heat loss in these small babies by using warm water. The patient should be monitored using standard equipment; ECG, non invasive blood pressure and a pulse oximeter. A rectal temperature probe can be used in the small babies to ensure maintenance of body temperature. The patient's chest and abdomen should be exposed so that the pattern of respiration can be easily observed. Emergency drugs and the airway trolley should be ready in theatre for immediate use if required. It should be noted that it is difficult to scavenge gases using this technique. Once surgery is complete, the patient is recovered in the same manner as described previously. If surgery has been extensive, and the surgeon and anaesthetist feel that there may be some oedema of the airway post-operatively, intravenous Dexamethasone may be given empirically prior to the end of the procedure, and again at six- to eight-hour intervals for up to three doses. This group of patients may benefit from high dependency care in the immediate post operative period.

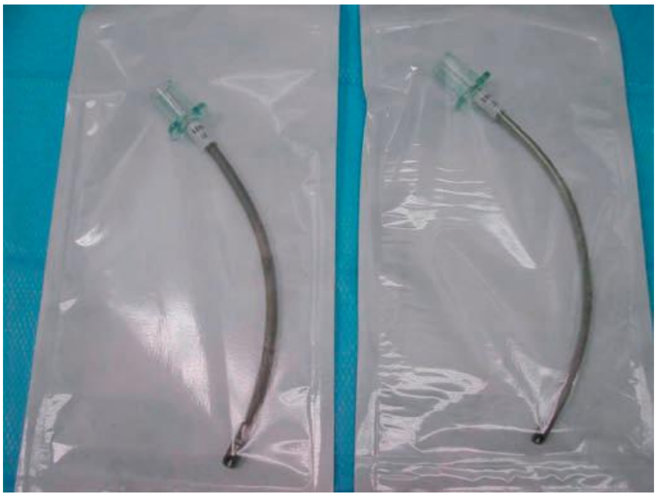


Fig. 11. Laser-Flex endotracheal tubes.

Whenever laser surgery is performed on the paediatric airway, it is safest in the hands of an experienced team. There should always be a plan to manage airway fires (Chapter 6). The most likely problems during the procedure are loss of the airway and/or apnoea. In the event of these happening, it becomes essential for good communication between all members of the theatre team, and the surgeon must assist the anaesthetist to rectify the situation. When the anaesthetist is happy that all is well, then surgery may continue (Sumner and Hatch, 1999).

6. Laryngotracheobronchoscopy

This is the 'bread and butter' of airway assessment. The Hopkins rod telescope attached by camera to digital video recording equipment now enables the surgeon (and everyone else in theatre) to see in high resolution and magnification the whole of the upper airway down to the carina and right and left main bronchus (Fig. 10C). Unlike adult rigid laryngoscopy, the paediatric laryngoscope or intubating laryngoscope is placed in the vallecula and as the scope is elevated, the Hopkins rod can be advanced under direct vision. Typically, four areas are viewed: the supraglottis, glottis, subglottis and trachea down to carina. Visualisation of the main bronchi is possible, however if inspection of the lower airways is necessary then flexible bronchoscopy may be carried out by your respiratory colleague (Fig. 12).

It is important to digitally record each patient for archiving and is advantageous to have the facility to print off images as well to place in patient notes.

7. Laser surgery in the paediatric airway

As the operating microscope with micromanipulator will be used, it is wise to check that an appropriate 400-mm lens has been attached and not a 250-mm usually used for grommet insertion and ear surgery. This will avoid the inconvenience of having to remove the micromanipulator to enable a lens change at a critical point during any procedure. It is good practice before any laser list to test the targeting HeNe beam and CO_2 laser for alignment. Traditionally a wet wooden spatula placed on a tray draped with moist material will suffice. One should never hold the spatula by hand for obvious safety reasons. Operating the laser within the paediatric airway is fundamentally similar to the adult scenario except for some subtle differences. In the adult the choice of wattage can be variable depending on whether you are debulking a tumour, or carrying out delicate phonosurgery on the vocal cords. In the paediatric setting, there is rarely a need for very high wattage. The same principles apply with regards to charring and with this in mind, it is the author's practice to utilise the superpulse setting. Once laryngotracheobronchoscopy has been completed and a diagnosis reached that necessitates laser treatment, a standard paediatric laryngoscope is inserted again into the vallecula. A suspension arm is attached to the laryngoscope and the opposite end placed on a Mayo tray secured to the operating table (Fig. 13).

In adults undergoing laser surgery surgeons are sometimes noted to place multiple layers of drapes on a patient's chest and using this as a cushion for the suspension arm. This is absolutely contraindicated in the paediatric setting, and indeed the authors' practice is to use the Mayo tray for all patients regardless of age. This makes for a much more secure platform, and will no doubt prevent restriction of chest movements during respiration. When satisfied with the position of the laryngoscope and a good view obtained, appropriate wet draping of the face, neck and head is carried out (Fig. 13). This step in preparation is vital in protecting the head and neck area from possible laser trauma (Ahmed *et al*., 2010). It is the responsibility of both nursing staff and surgeon to ensure that all personnel within theatre are wearing appropriate eye protection. The 'laser in use' sign outside theatre must be illuminated and from hence forth, no additional personnel should be allowed into theatre without protective eyewear, while the laser is in operation (Champion, 2000; Baxter, 2006). Once all safety

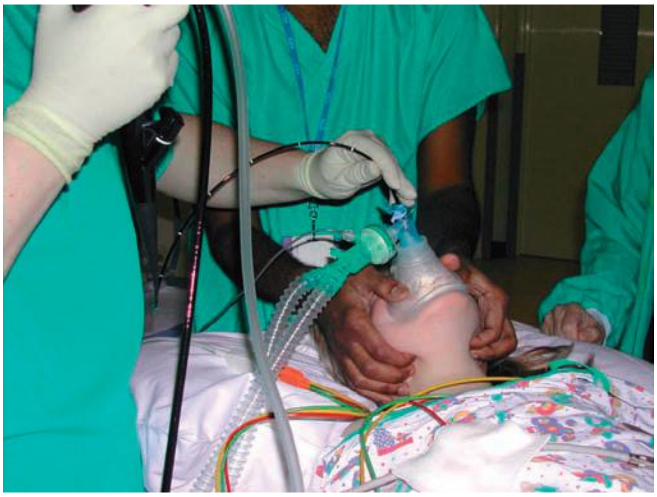


Fig. 12. Transnasal flexible bronchoscopy.

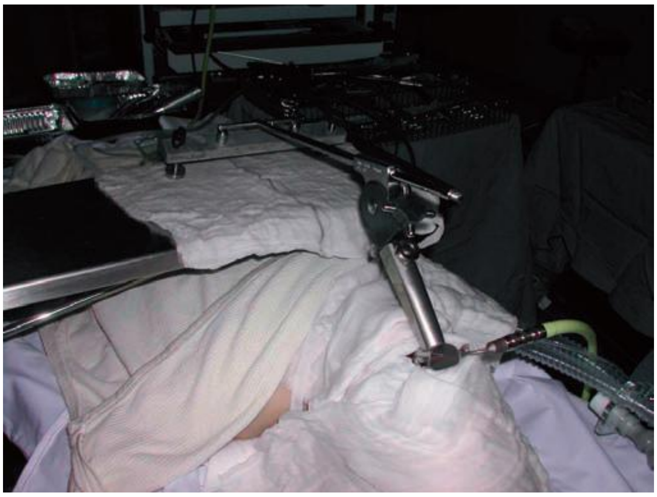


Fig. 13. Suspension arm setup with wet draping.

measures are in place lasering may begin. When the surgeon has targeted the appropriate area of tissue, they must relay a clear instruction to switch the laser on to the laser operator. Once the surgeon has completed a sequence of laser treatment, it is again his or her responsibility to instruct the laser operator to set the laser to standby. Another area of tissue is targeted, and the sequence commences again and so on.

8. Airway pathology and laser surgery

Some of the conditions below have been discussed in Chapter 19. However, it is worth reminding ourselves of the main pathologies that are amenable to laser therapy within the paediatric airway and also to note where extra care must be taken.

8.1. Laryngomalacia

Perhaps the most common condition treated with CO_2 laser is laryngomalacia. This condition accounts for approximately 60-70% of cases of congenital stridor. The classic features of a tall tubular (omega-shaped) epiglottis, short aryepiglottic folds and redundant mucosa overlying the arytenoid cartilages all contribute to partial obstruction to varying degrees (Fig. 14A, B).

Neonates and infants with severe laryngomalacia and concomitant failure to thrive have been shown to show good signs of recovery following aryepiglottoplasty (Toynton *et al*., 2001). Various techniques have been adopted over the years. Laser assisted aryepiglottoplasty is widely used for the management of this condition (Fig. 15A, B).

The procedure consists of dividing the shortened aryepiglottic folds and often debulking redundant mucosa overlying the arytenoid cartilages. This releases the tension on the supraglottic structures and negates any excess mucosal tissue that has a tendency to collapse towards the glottis during inspiration. On occasion, the epiglottis can also be drawn backwards over the glottis even after lasering to the aryepiglottic folds has been performed. In such cases, it is sometimes useful to perform some linear lasering in the region of the vallecula (Whymark *et al*., 2006). With a defocused beam it is possible

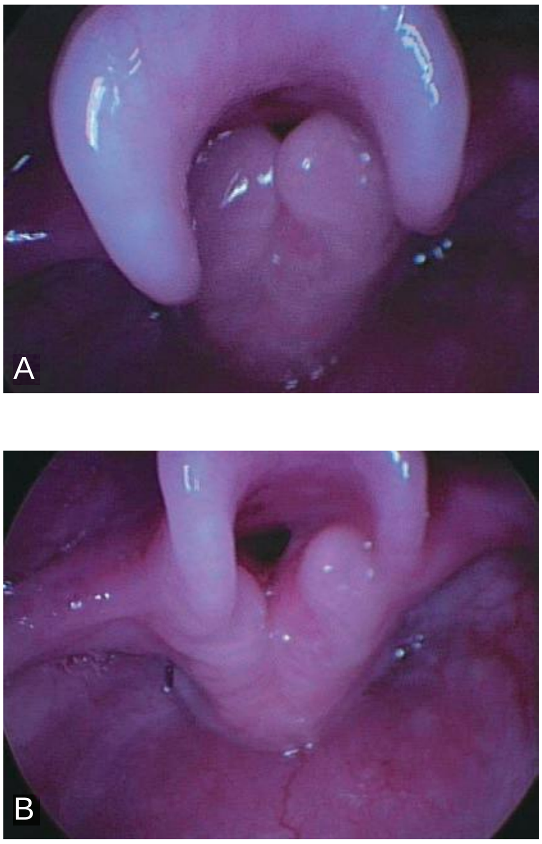


Fig 14. A, B. Laryngomalacia.

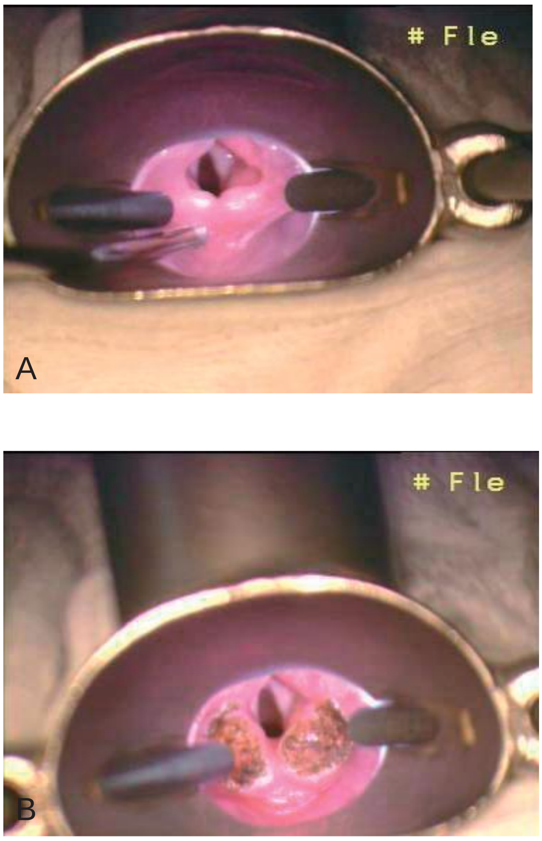


Fig. 15. A, B. Pre- and post-laser treatment.

to shrink tissue in this area, thereby pulling the epiglottis more anteriorly.

8.2. Subglottic haemangioma

Haemangiomas involving the paediatric airway are almost always in the region of the subglottis (Fig. 16).

The natural history of such lesions is to regress in time, typically by 18-24 months of age. Management of these lesions has included the use of systemic steroids over a one-to-two-week period, or surgical tracheostomy and a watch and wait policy until involution of the lesion and safe decannulation. Laser treatment has also been advocated by some (Remacle *et al*., 1989). However, some evidence suggests little difference between this and tracheostomy (Chatrath *et al*., 2002). Caution must be taken, and potential laser cases must be carefully selected to avoid possible long-term post-operative complications. It is generally accepted that small lesions are amenable to CO_2 laser treatment, but larger lesions may pose more of a problem and may result in subglottic stenosis from overzealous lasering of a large area. In more recent years, the observation of resolution of subglottic haemangiomas with the use of propranolol has been noted (Jephson *et al*., 2009). Large subglottic haemangiomas can at times compromise the airway to such a degree that it is impossible to perform laser vaporisation simply due to the fact that oxygen saturations cannot be maintained, and tend to decrease very rapidly upon airway instrumentation. The promising effects of β-blockers has provided clinicians with the possible option of attempting more rapid involution of haemangiomas following tracheostomy, instead of performing laser vaporisation.

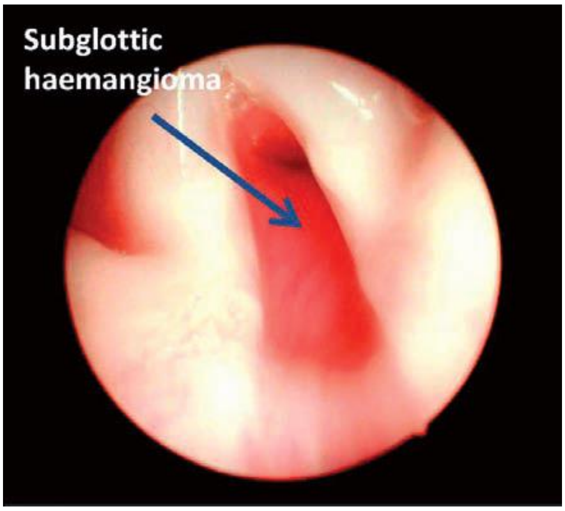


Fig. 16. Subglottic haemangioma.

8.3. Recurrent respiratory papillomatosis

As discussed in Chapter 9, respiratory papillomatosis (Fig. 17) can be very well controlled with the CO_2 laser (Gutierrez Castillo, *et al*., 2010; Pia *et al*., 1997).

Some also advocate adjuvant α-interferon use (Mattot *et al*., 1990). Care again has to be taken in the use of CO_2 laser, to avoid excessive use and with too high settings that can result in complications such as webbing and subglottic stenosis. Chapter 60 covers emerging technology for recalcitrant cases: KTP (Zeitels *et al*. 2006), Nd:YAG (Janda *et al*. 2004) and pulsed-dye laser (Zeitels *et al*., 2004) treatments have also been shown to be effective.

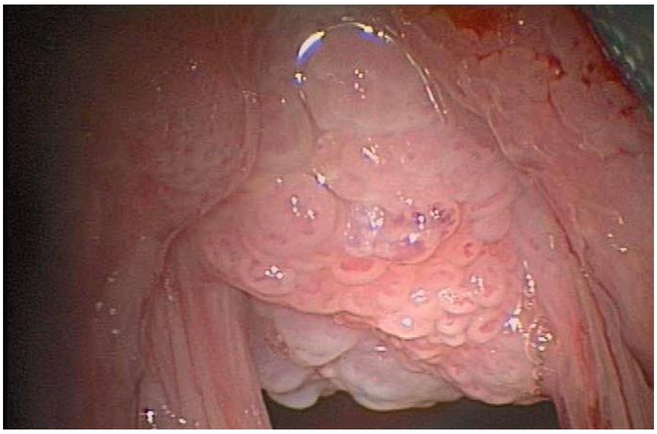


Fig. 17. Recurrent respiratory papillomatosis.

8.4. Epiglottic cysts, saccular cysts, laryngocoeles

Large cystic structures within the paediatric supraglottis may compromise the airway (Fig. 18).

Saccular cysts are rare mucus filled structures that may cause obstructive symptoms in the child. These are always diagnosed endoscopically and management usually consists of deroofing (marsupialisation) of the cyst with a wide margin. The CO_2 laser can perform this very well indeed by simple vaporisation of the cyst roof. Laryngocoeles are air filled structures, however only the internal form may

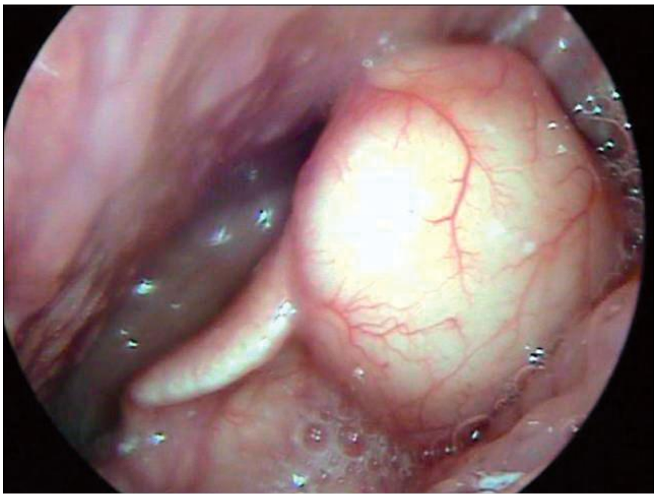


Fig. 18. Epiglottic cyst.

be seen on endoscopy as it is contained within the boundaries of the thyroid cartilage (Bailey, 2007). These lesions may again be marsupialised with the laser, but care must be taken to ensure that the internal form of the cyst is not connected to an external component by way of imaging.

8.5. Subglottic stenosis

The majority of congenital subglottic stenosis cases are managed conservatively (Fig. 19).

The manner of this conservative approach is dependent on the grade of the stenosis (Table 3) and also on the degree of airway compromise.

In the absence of the latter, infants may simply be observed. If, however, there is significant airway compromise then tracheostomy is necessary after which a watch-and-wait policy is implemented as the stenosis is expected to enlarge with age. In adults, laser treatment and dilatation has been implemented with some cases performed without general anaesthesia (Leventhal *et al.*, 2009). Any form of laser management with or without dilatation in a congenital *cartilaginous* stenosis situation is absolutely contraindicated. Such practice inevitably results in worsening of the original stenosis and it is worth remembering that the cricoid is a continuous ring of cartilage that cannot be stretched (Bailey, 2007). For further coverage of this topic, see Chapter 16.

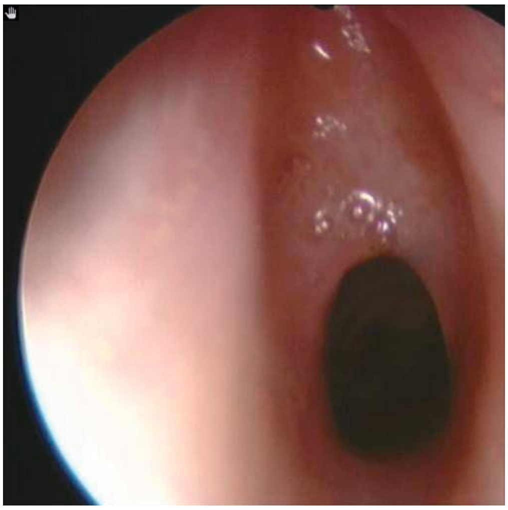
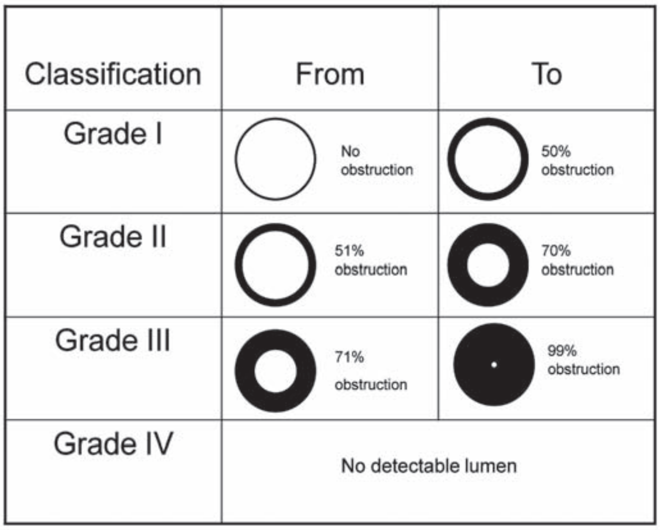


Fig. 19. Subglottic stenosis.

Table 3. Cotton grading.



Classification	From	To
Grade I	No obstruction	50% obstruction
Grade II	51% obstruction	70% obstruction
Grade III	71% obstruction	99% obstruction
Grade IV	No detectable lumen	

9. Paediatric and neonates tracheostomy

Stridor in a child usually signifies some degree of upper airway resistance. The commonest cause in neonates and infants is laryngomalacia. As we know this is not the only possible aetiology. In addition, some patients also have significant co-morbidities and may suffer from complex cardiac disease. Although the aetiology of conditions may vary between continents, the outcome is still the same and the compromised airway must be appropriately handled. Often, the only immediate or long-term management available is a tracheostomy. There will also be instances where high-tech medicine is available, but some distance away, and therefore, tracheostomy is a short term option before a definitive management is available.

Tracheostomy is not without hazards. The successful outcome following tracheostomy will depend on aftercare facilities, which may be very poor indeed.

Very often due to the absence of home care programmes, children once having had a tracheostomy will need to remain hospitalised. The authors have therefore included some practical points pertaining to tracheostomy for a quick reference.

9.1. Paediatric tracheostomy

Tracheostomy in the paediatric patient is not too far removed from the adult scenario and it may be argued that some aspects are easier to perform. It goes without saying that the neck of an infant is much smaller and as such important structures are therefore closer to the midline. The carotid vessels for example may be easily damaged if straying a little too far laterally. That said, blunt dissection towards the trachea is less of an effort compared to that in the adult and a much smaller thyroid gland isthmus can be quickly divided with bipolar diathermy. It is also important to recognise the thymus gland which may appear inferiorly from the thoracic inlet, and also to be aware of the possibility of high innominate vessels.

The first initial step when forced to consider a tracheostomy in an infant or child is positioning of the patient. The neck must be extended as much as is safely permitted. This can be facilitated with a shoulder roll. Often in neonates and infants a combination of short neck and abundant fat can reduce the exposure of the anterior neck. In these situations placing tape beneath the chin usually gives the much needed extra exposure required (Fig. 20).

Next, a selection of tracheostomy tubes of varying sizes should be available (Fig. 21). Calculating the size of tube to use can be simplified with the use of the following formula:

$$\text{Size of tube} = \text{age}/4 + 4$$

Thus, a four-year-old child would require a size-five tube. It is usual practice to also select a tube a size smaller and larger than this, so, in this example, sizes 4.5, 5.0 and 5.5 should be available. The skin is infiltrated with local anaesthesia and a standard horizontal skin incision is made half way between the cricoid cartilage and the suprasternal notch. There is a tendency sometimes to make a large skin incision, however, this is rarely necessary as the tissues are very pliable and will stretch adequately to give good exposure. It is advisable to clear away as much subcutaneous fat from the wound as possible. This will facilitate a much clearer view of deeper structures and will line the tracheostomy wound with the inverted skin edges. Blunt dissection with a small surgical clip is often all that is needed to expose the trachea. Again, if the thyroid isthmus is present this can be divided with diathermy. Stay sutures may be inserted at this point on either side of the planned tracheostomy site but these must be placed completely through the tracheal wall as otherwise they will have a tendency to tear through. A vertical incision over the third to fourth cartilage rings will then expose the endotracheal tube. A maturation suture (Craig *et al*,

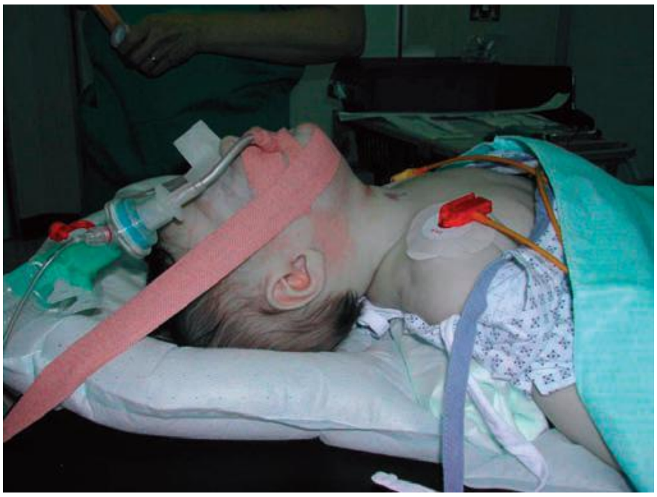


Fig. 20. Positioning of head for tracheostomy, secured with tape.

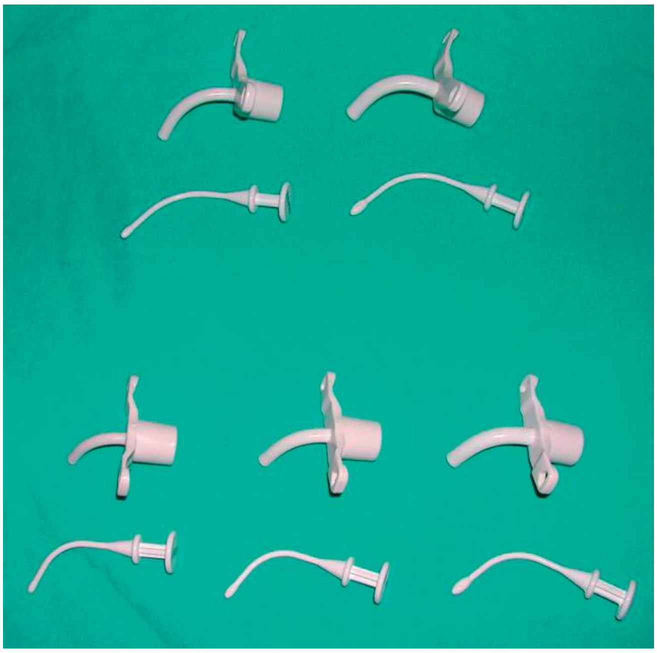


Fig. 21. Selection of paediatric tracheostomy tubes. →

2005) may then be inserted at the midpoint of the inferior skin edge and passed to the inferior end of the tracheal incision. This will also help in inverting the skin edge and promoting epithelialisation of the tract. At this point insertion of the tracheostomy tube may be undertaken. Elevation of the stay sutures will draw the trachea forward and also open the tracheotomy. Upon instructing the anaesthetist to withdraw the endotracheal tube, insertion of the tracheostomy tube may be carried out once the tip of the tube has disappeared. Once the anaesthetist is happy that an adequate CO_2 trace is obtained and that there is no gross leak, the tube may be secured. It is advisable to use tied linen tapes as these are less likely to be inadvertently undone as is the case with velcro straps. Close aftercare is essential in the initial two to three days after tracheostomy tube insertion. If displaced, the still raw surgical wound may close down rapidly within 24 hours. There is also an increase in secretions produced so necessitating regular suctioning of tubes.

10. Conclusion

Paediatric airway management requires a multidisciplinary approach to ensure that the best possible care is delivered in the safest manner. A clear dialogue must be established between all professionals involved, including a clear understanding of the pitfalls that may occur and how to avoid them. Forward planning for each individual case is essential, and involvement of immediate family is crucial for long-term benefits. Provision of an airway service cannot be instigated on a whim, but requires highly trained medical personnel working within a robust infrastructure that can also provide additional support from all related departments. Safety and placing the child first is always paramount, and although laser surgery to the infant larynx can pay large dividends, it is prudent to remember that sometimes doing nothing and adopting a conservative approach can be just as rewarding.

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MCQ – 18. Paediatric laryngo-tracheal airway

1. In paediatric population, cricoid is at
    a. C2
    b. C4
    c. C5
    d. C6
    e. Between C4 and C5

2. The narrowest part of the airway in children is
    a. The supraglottis
    b. The glottis
    c. The subglottis
    d. The trachea
    e. None of the above

3. As per Poiseulle's law, the resistance to flow within a tubular structure
    a. Is directly proportional to the radius of that structure
    b. Is inversely proportional to the radius of that structure
    c. Increases to the power of two ($1/r^2$:1 mm obstruction increases resistance by twice as much)
    d. Increases to the power of three ($1/r^3$:1mm obstruction increases resistance by four times as much)
    e. Increases to the power of four ($1/r^4$:1 mm obstruction increases resistance by sixteen times as much)

4. In neonates and very young children, the airway is extremely narrow. The size of the endotracheal tube is estimated, as a rough guide to be
    a. Age/4 + 4
    b. 4.0 mm
    c. 4.5mm
    d. 5.0 mm
    e. Such estimates are useful but do not take into account the reduction in the lumen due to obstruction and therefore a selection of tubes between 4 mm and 6 mm should be available

5. A dedicated anaesthetic tracheal tube such as the Laser-Flex tube
    a. Is totally fire-proof
    b. Is fire-safe
    c. Will catch fire if struck with a laser beam
    d. Will ignite if struck with a laser beam
    e. Best avoided in paediatric obstructed airway since it severely restricts the surgical procedure with the laser. Instead, adequate anaesthesia can be maintained with a small nasal catheter advanced up to the nasopharynx

6. A maturation suture
    a. Is a stay suture on either side of the tracheostomy site
    b. Is a suture running through the inferior skin incision to the inferior end of the tracheostomy slit
    c. Makes insertion of tracheostomy tube easier, should it be accidentally displaced
    d. Helps to exteriorise the stoma which is intended to be permanent
    e. Is a suture which goes through the flange of the tracheostomy tube and stitched to the skin, to ensure that the tube is not accidentally displaced

7. The correct focal length for the objective lens of the operating microscope for laryngeal procedures is
    a. 250 mm
    b. 350 mm
    c. 400 mm
    d. 450 mm
    e. 500 mm

Chapter 19

Neonatal laryngopathy

M. Remacle and V. Oswal

1. Laryngomalacia

1.1. Introduction

Congenital laryngeal stridor, also known as laryngomalacia, is caused by varying degrees of supraglottic collapse of the soft tissue during inspiration. The disorder is thought to be due to a deficient neuromuscular maturation (Archer, 1992; Thompson, 2007). Laryngomalacia can be associated with other congenital anomalies (Chen *et al*., 2006; Daniel, 2006; Munson *et al*., 2011). Laryngomalacia is the most common cause of stridor in infancy but it can also affect adults (Gessler *et al*., 2002). Laryngomalacia is prevalent among children presenting with symptoms of sleep-related-disordered breathing (Thevasagayam *et al*., 2010).

The collapse is often restricted to the free margins of the aryepiglottic folds, the epiglottis and the arytenoids, in varying degrees (Olney *et al*., 1999; Shah and Wetmore, 1998). A classification has been proposed according to the direction of the collapse: type A (postero-lateral), type B (complete), and type C (anterior) (Lee *et al*., 2007). Episodes of microaspiration are possible (Midulla *et al*., 2004).

1.2. Examination

Flexible fibreoptic examination shows short aryepiglottic folds, redundant and loose arytenoid mucosa, and an epiglottis that frequently curls up on itself (Lima *et al*., 2008).

1.3. Symptoms

The presenting symptom is stridor of varying severity, occurring during the first few months of life. In mild cases, the only symptom is that of stridor, and body growth is normal. In cases of intermediate severity, there is breathlessness during feeding, failure to thrive and recurrent broncho-pulmonary infections. Severe cases present with episodes of cyanotic attacks, hypoxia, and even respiratory arrest (Remacle *et al*., 1996; Shah and Wetmore, 1998; Thompson, 2010).

Reflux is associated with upper airway symptoms in children (Rosbe *et al*., 2003).

The airway fluoroscopy is of limited use compared to endoscopy for the diagnosis and evaluation of laryngomalacia (Huntley and Carr, 2010).

1.4. Management

In most cases of mild and intermediate severity, medical management with anti-reflux treatment may be sufficient. In refractory and severe cases, surgical intervention is advised (Thompson, 2010). Most severe cases should undergo immediate surgery (Remacle *et al*., 1996). Under general anaesthetic, the site of collapse is confirmed during the inspiratory phase of spontaneous breathing. Placing a suction tip in the subglottis mimics the inspiratory phase by creating negative subglottic pressure and results in gross prolapse of the soft tissue into the supraglottis. The sucking effect is no longer seen after successful management.

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The anaesthetic technique depends upon the expertise of the team, but HFJV is most useful in such cases. Alternatively, an apnoeic technique is useful for laser surgery.

Surgical endoscopic management using cold instruments was proposed by Variot as early as in 1898. The current management is carried out with cold steel instruments, or with the laser. Although, the procedure is variously named as supra-arytenoidectomy (Katin and Tucker, 1990), supraglottoplasty (Groblewski *et al*., 2009) and aryepiglottoplasty (Hadfield *et al*., 2003), it basically consists of excision or CO_2 laser vaporisation of the aryepiglottic folds (Roger *et al*., 1995). Excision or vaporisation of redundant arytenoid mucosa and the free margins of the epiglottis are also treated similarly (Polonovski *et al*., 1990).

The obvious advantage of lasers over microscissors is that the laser procedure is invariably bloodless (Holinger and Konior, 1989). The aryepiglottic folds are vaporised up to the ventricular folds (Fig. 1). If the arytenoid mucosa is removed, care must be taken not to denude the crico-arytenoid joint in order to avoid subsequent granuloma, arthritis or ankylosis. It is important to adhere to the phonosurgical parameters of the laser in order to avoid any permanent injury to the larynx. Fibre-guided lasers such as the diode (Fanjul *et al*., 2008), KTP or the thullium (Ayari-Khalfallah *et al*., 2008) can also be used for the section, but they have relatively deeper penetration.

In some severe cases, an epiglottic suture can be placed transversely on the lingual surface of the epiglottis for unfolding the epiglottis and shifting apart the adjacent aryepiglottic folds, thus correcting the infantile shape of the epiglottis (Fajdiga *et al*., 2008). Epiglottoplasty on the base of tongue using single suture stitches following laser-surgical vaporisation of the corresponding mucosal areas of the epiglottis and the base of the tongue has also been proposed (Werner *et al*., 2002).

In the authors' hands, the CO_2 laser remains the ideal instrument for this surgery even if other instruments like the microdebrider can be efficient (Groblewski *et al*., 2009; Lee *et al*., 2007).

The postoperative results are often spectacular. There is an immediate improvement in the symptoms of stridor. In the long term, the child begins to thrive, and is free of any further bronchopulmonary infections. Aspiration is possible postoperatively and is not related to the technique or instrumentation used (Rastatter *et al*., 2010; Schroeder Jr. *et al*., 2008).

In cases where a concomitant disorder such as tracheomalacia, a narrow cricoid lumen, or an allergic asthma is present, the results of surgery are less spectacular.

2. Subglottic haemangioma

2.1. Introduction

Subglottic haemangiomas are one of the most frequent benign tumours in children. They are usually located in the cricoid area, and the cricoid itself may be invaded with varying degrees of severity. The vast majority of these lesions are noted in the neonates (Garfinkle and Handler, 1980). Flexible fibreoptic examination shows a cherry-coloured lump obstructing the subglottic lumen, varying in severity. The treatment outcomes are based on the following measures:

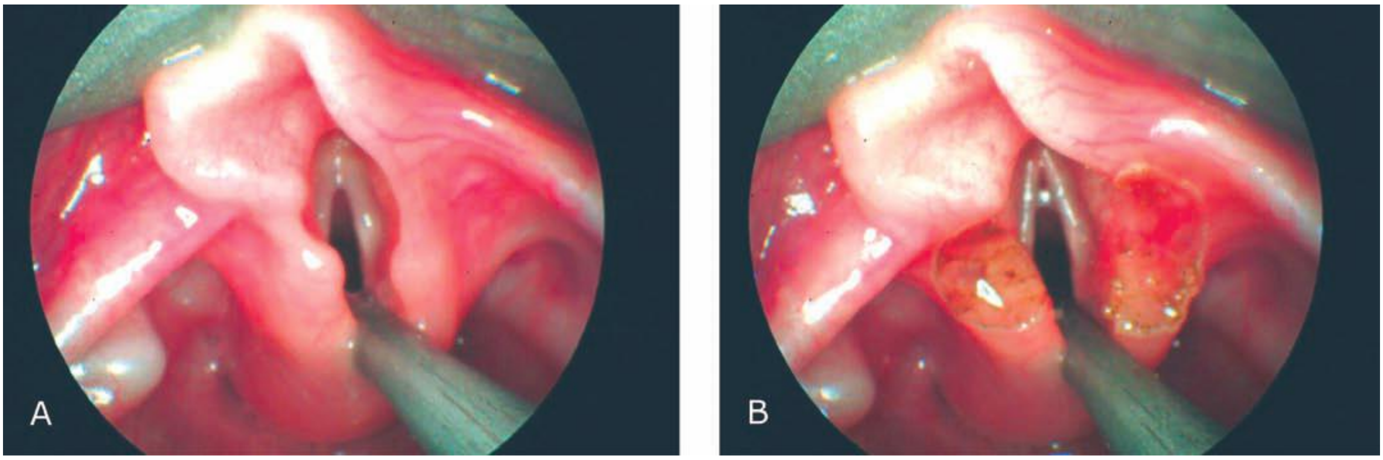

Fig. 1 A. Laryngomalacia; B. Postoperative view after trimming of both aryepiglottic folds.

- Resolution of symptoms
- Reduction of airway obstruction
- The need and duration of intubation, tracheostomy, decannulation
- Need of further treatments
- Occurrence of complications.

2.2. Management

Until recently, a variety of surgical management strategies were considered and no single treatment modality was accepted as ideal: Systemic steroids (Al-Sebeih and Manoukian, 2000), intralesional steroid injection, laser ablation with CO_2 (Nicolai *et al*., 2005), KTP (Kacker *et al*., 2001) and Nd-YAG lasers (Fu *et al*., 2007), microdebrider , interferon (Kontzoglou *et al*., 2002) and open surgical excision (Lee and Messner, 2007) have all been utilised (Pransky and Canto, 2004). Propranolol, a beta-blocker commonly used in cardiology that may induce endothelium vasoconstriction and inhibit endothelial proliferation, is now considered the first line of treatment (Leaute-Labreze *et al*., 2008; Leboulanger *et al*., 2010; Peridis *et al*., 2011; Truong *et al*., 2010): one French multi-centric study on 14 cases showed propranolol to be effective in all cases with a reduction of the airway obstruction from 68% to 12 % after four weeks (Leboulanger *et al*., 2010). Other medical treatments (*e.g*., steroids) could be stopped. However, recurrences are possible after early treatment interruption and development of resistance to propranolol has been reported (Canadas *et al*., 2010).

The proposed dose is two mg/kg/day (Jadhav and Tolat, 2010; Missoi *et al*., 2011). Another cardioselective beta-blocker acebutolol, eight mg/kg/day can also be easily administered in oral form twice-a-day only, with a dose that is adaptable according to the growth of the child without side effects (Blanchet *et al*., 2010).

Where surgical intervention is required, endoscopic laser surgery is the therapeutic option that most approaches the stated objectives.

The aim of laser surgery is to restore a useful airway by shrinking the haemangioma. Complete excision of the lesion is neither required (Remacle *et al*., 1989), nor possible if it invades the cricoid cartilage. Although the laser cannot suppress or reduce the frequency of sudden inflammatory episodes, it can reduce the severity of the attack, help reduce the use of steroids, and avoid the need for intubation.

Surgery is carried out under general anaesthesia, with HFJV or an apnoeic technique. Initial intubation of the child is useful to reduce the size of the lesion by compression. The KTP and Nd:YAG lasers cause deeper thermal damage than the CO_2 laser, which is therefore the instrument of choice (Re *et al*., 2003; Sie *et al*., 1994). However, fibre-delivered lasers have a considerable advantage of transmitting the energy directly to the site of the lesion and sparing the vocal folds of any thermal damage (McCaffrey and Cortese, 1986). Saetti *et al*. (2008) reported 95% success rate using fibre transmissible diode laser.

When the CO_2 laser is used, the acublade® is extremely useful (Remacle *et al*., 2005). It is advisable to start with single pulses of 0.05-0.1 seconds with the circular ablation mode, in continuous wave. Lasing produces blanching and substantial shrinkage of the haemangioma, with subsequent enlargement of the airway. Endoscopic laser management may not be possible for larger lesions, which will require open surgery (Lee and Messner, 2007). The undersurface of the vocal fold and the subglottic area are difficult to reach with the free beam CO_2 laser, even after rolling the vocal fold upwards and laterally. Fibre-guided lasers are useful, provided that low power is used in order to avoid deeper thermal penetration.

3. Congenital mucous cysts

A saccular or congenital cyst of the larynx is a mucus-filled dilatation of the laryngeal saccule and can distort the aryepiglottic fold, the false cord or the laryngeal ventricle. Intracystic cartilaginous tissue is sometimes identified (Suhonen *et al*., 1984). Present at birth, these cysts suddenly enlarge due to infection, and bulge through the pharyngolaryngeal wall, thus occluding the supraglottic lumen. The most common symptom of the laryngeal cyst is respiratory distress with inspiratory stridor and the diagnosis can usually be made by laryngoscopy. Management is by CO_2 laser-assisted marsupialisation.

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MCQ – 19. Neonatal laryngopathy

1. Laryngomalacia
    a. Is the most common congenital disorder affecting children
    b. Is the second most common congenital disorder after recurrent respiratory papilloma, causing stridor in children
    c. Severe cases require immediate tracheostomy
    d. Urgent laryngoscopy and excision of the ary-epiglottic fold is the treatment of choice in severe cases
    e. In severe cases, staged surgery is necessary

2. Laryngomalacia
    a. The most common symptom is stridor
    b. Stridor is biphasic
    c. Failure to thrive is due to inability to feed adequately due to breathelessness
    d. Failure to thrive one of the indications for surgical intervention
    e. Cyanotic episodes indicate severity of condition and requires urgent management

3. Laryngomalacia
    a. Intubation anaesthesia provides a secure airway while surgery is being carried out
    b. Jet ventilation and apnoeic technique is most adequate and preferred method
    c. CO_2 laser is particularly useful to ablate redundant mucosa bloodlessly
    d. In a severely curled epiglottis, partial epiglottectomy is a preferred option
    e. In a severely curled epiglottis, applying a stitch on the lingual surface to straighten it is a preferred option

4. Subglottic haemangioma: in symptomatic cases, the first line of treatment is
    a. Systemic steroids or intralesional steroid injection
    b. Laser ablation with CO_2 KTP and Nd-YAG lasers
    c. Microdebrider
    d. Open surgical excision
    e. Propranolol, which may induce endothelium vasoconstriction and inhibit endothelial proliferation

5. Subglottic haemangioma: transoral laser surgery
    a. Is carried out when medical management fails
    b. Is carried out when cricoids is involved
    c. Is carried out using a fibre transmissible laser such as the KTP or Nd: YAG
    d. Is carried out with a free beam CO_2 laser
    e. Is carried out with the CO_2 laser delivered via waveguide

6. Subglottic haemangioma
    a. External surgery is necessary only in large multiple lesions
    b. External surgery is necessary when croicoid is involved
    c. External surgery is rarely called for
    d. Trachesotomy may be necessary for large lesions
    e. All of the above

Section III: Lasers in Endonasal Surgery

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Chapter 20

Endonasal laser applications

V. Oswal, J.U.G. Hopf, M. Hopf and H. Scherer

1. Introduction

Surgical procedures in the nose, using cold instruments, are inherently difficult. The mucosa is extremely vascular and intraoperative bleeding is profuse. Although it can be minimised by decongesting the mucosa, any residual bleeding needs to be continuously removed in order to maintain surgical progress. Removal of tissue is gross and preservation of normal delicate respiratory mucosa, difficult. Nasal packing, used to control postoperative bleeding, is very uncomfortable for the patient and requires an inpatient stay. Procedures carried out under local anaesthetic are usually less bloody and, generally, more surgeons are adopting these, possibly driven by cost considerations.

In recent years, minimally invasive nasal surgery has become available due to the introduction of the endoscope and powered instruments. Middle meatus disease is now managed by functional endoscopic sinus surgery (FESS), which is practised widely.

Medical lasers were introduced into clinical practice in the 1970s, and the CO_2 laser, due to its shallow thermal damage zone, was quickly adopted for laryngeal surgery by otolaryngologists. Refinements such as small spot size and superpulse mode ensured its continuing role as the workhorse laser in otolaryngology. However, application of the CO_2 laser in rhinology was slow because of a number of factors, which are described below. Introduction of fibre-transmissible wavelengths in the 1980s helped to revive interest, and various lasers were quickly adopted in the management of nasal pathology. This chapter provides a general overview of the current practice of laser surgery in rhinology, while other chapters in this section deal with the laser management of specific disease entities.

2. Why lasers for nasal surgery

Conventional punch or grasping forceps bite much deeper before tissue can be removed. Thus, there is a potential for damage to the tissue beyond direct visual control. Bleeding caused by these conventional methods of tissue removal further obscures the view, and the procedure becomes somewhat 'blind'. Lasers offer certain unique advantages in endonasal surgery of the middle meatus complex (MMC). The relatively bloodless field in the MMC offered by lasers means that the surgical procedure is under better visual control (Fig. 1A,B). The slim fibre delivery system directed by a multifunctional endoscopic application device offers an excellent view of the operating site and surrounding structures, allowing a greater margin of safety. Using the correct wavelength and its parameters limits any deeper spread of the energy (Fig. 2A,B). The beam is moved over the target like a paintbrush, and progress assessed periodically, between laser strikes. This

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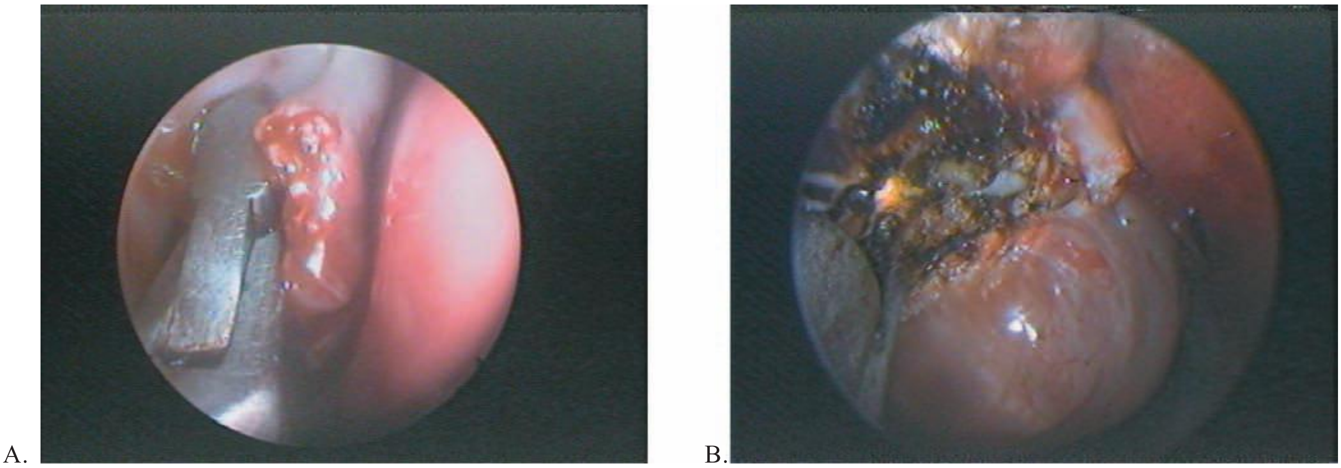

Fig. 1. A. Conventional cold instrument bites much deeper before tissue can be removed. B. Laser vaporisation removes tissue layer by layer.

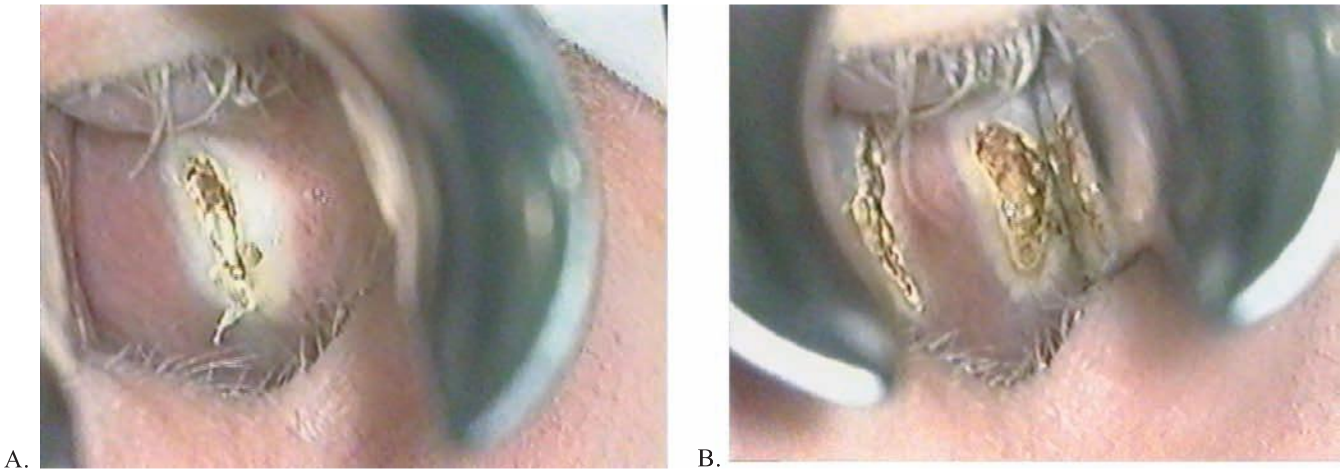

Fig. 2. A. Ho:YAG laser turbinate reduction showing instant loss by vaporisation, surrounded by zone of coagulation. B. Using correct wavelength and its parameters limits collateral spread of the energy.

advantage is particularly welcome in revision surgery of the MMC, where the anatomy is often distorted and obscured by scar formation.

Similar advantages are observed in surgery for turbinate hypertrophy. The bloodless field gives a superior view of the operating site and reduction of the turbinate can proceed under complete visual control – something that can never be achieved with conventional surgery (Fig. 3A,B). Likewise, surgery for choanal atresia can be carried out bloodlessly under complete visual control (Fig. 4). Thus, there is little doubt that laser technology offers considerable advantages over conventional methods for endonasal surgery. If the equipment is available, then every effort should be made to acquire expertise in its use for the management of a wide range of nasal pathology.

Laser surgery involves destruction of tissue by two processes: instantaneous vaporisation and delayed tissue loss by coagulation. By judiciously choosing the laser wavelength and the parameters, it is possible to vary each of the two components.

The term laser biophysics encompasses the interaction between the properties of a laser on the one hand, and that of the tissue on the other. The laser properties are governed by the incident wavelength, mode of application (continuous versus chopped/pulsed), application procedure (contact versus non-contact), power and energy density, and the duty cycle (on/off time). The tissue properties are governed by the make-up of that particular tissue with the various chromophores. Absorption of the laser by the chromo-

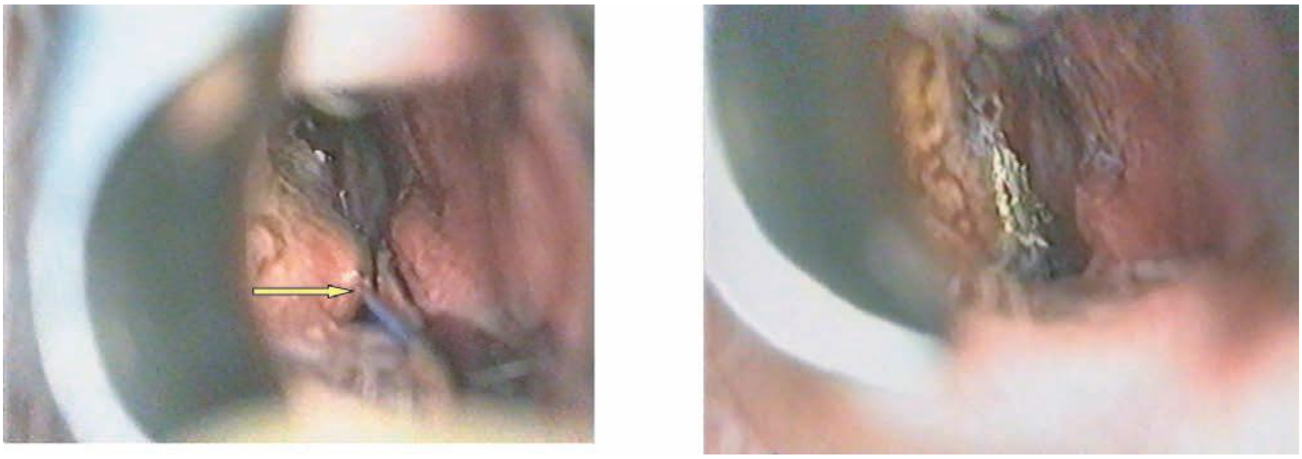

Fig. 3. Reduction of enlargement of the posterior end of inferior turbinate with the Ho:YAG laser delivered via 365 µm fibre (arrow).

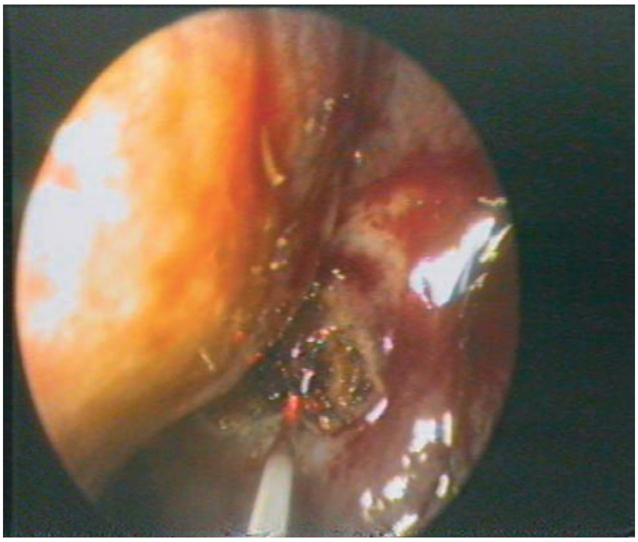

Fig. 4. Surgery for choanal atresia can be undertaken bloodlessly under complete visual control.

phores leads to the effect, which, although variable due to a number of factors involved, can, to a certain extent, be predicted. The surgical outcome can therefore be predictable and consistent. In order to achieve dependable results, it is imperative that the surgeon understands the properties of the laser and also of the target tissue, so that the surgical outcome is consistent with the aim of the surgery. For example, in a case of olfactory neuroblastoma with troublesome epistaxis, the aim is to obliterate the offending blood vessel. Conventional techniques involving ligation or embolisation would carry a high risk and morbidity. The Nd:YAG laser, with its excellent coagulative properties, was used by one of the authors (HS) to effect occlusion of the blood vessels, with minimum morbidity and the desired effect.

3. Review of the literature

A review of the literature shows that it is not necessary to have a wide range of wavelengths for the management of nasal pathology. As long as the surgeon understands the tissue interactions and the limitation of any particular laser, most pathology can be adequately managed with a fibre transmissible wavelength.

3.1. Reduction of turbinates

Reduction of turbinate hypertrophy is probably the most common condition treated with the laser. Chapter 22 covers a detail discussion on this topic.

Lenz (1975; 1977a; 1977b), one of the pioneers of endonasal laser surgery, used the argon laser as early as 1977 for reduction of inferior turbinate.

In their prospective randomised study comparing laser cauterisation and submucous diathermy, McCombe and Cook (1992) found that the laser produced superior results in terms of the lasting improvement of subjective symptoms.

The high scatter of the Nd:YAG laser (1.064 nm) and penetration of the energy up to 7 mm deep may be judiciously used to reduce the bulk of the submucous tissue in enlarged hypertrophy of the turbinate. The experience in the use of the

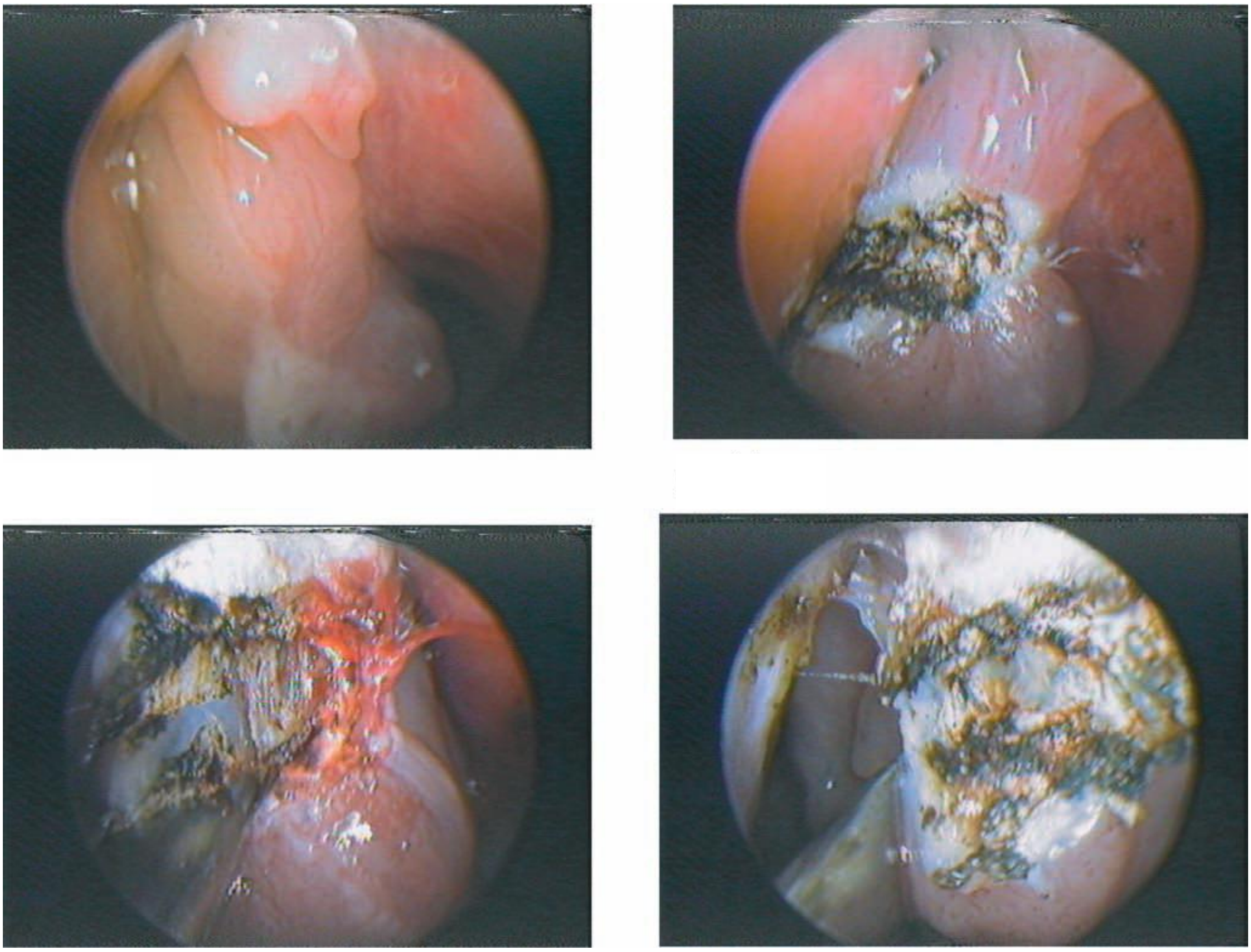

Fig. 5. The bulk of the polyp can be reduced nearly bloodlessly so that the anatomical landmarks are clearly displayed.

Nd:YAG laser by one of the authors (JH) compares favourably with that reported by Lippert (1992, 1995, 1996, 1998), Jovanovic (1995), and Krespi (1994).

Fukutake *et al.* (1986, 1993) presented a large study of laser surgery in the treatment of vasomotor rhinitis. In a total of 1,000 patients receiving CO_2 laser therapy, he found excellent outcomes in 46%, good results in 34%, and unchanged status in 20%.

Mittelman (1982) described the application of the CO_2 laser in patients with turbinate hyperplasia and synechiae but found lack of fibre transmission a disadvantage.

Selkin (1985) focused mainly on clinical applications of the CO_2 laser in continous wave mode. Due to its poor coagulation property, the author found that the CO_2 laser was not very suitable for endonasal surgery.

In a comparative study, Lippert and Werner (1998) reported success rates of 85.7% and 77.1% (six months and five years, respectively) with their own CO_2 laser operating technique. The reported rates of success were clearly higher than those obtained in their work with the Nd:YAG laser (66,6% and 64,6%, respectively). In their opinion, for comparison, the results of laser surgery should be interpreted over a period at least two to three years, a period when symptoms of vasomotor rhinitis may recur following conventional surgery.

In 1991, Levine reported on 425 patients treated with the KTP laser. 71.1% were asymptomatic and needed no topical decongestant during the 2-4 years of follow up. Further 20.2% were asymptomatic, but occasionally administered nasal drops, whereas no improvement was observed in 8.7%. There was no deterioration in any patients.

3.2. Nasal polypi

In 1985, Lenz reported 'laser carbonisation' of small, sessile, nasal polypi with the argon laser.

Ohyama (1989) used the Nd:YAG laser to treat nasal polyposis. A ceramic tip was used on the laser fibre to scatter the energy on the surface of the tissue, thereby limiting the depth of penetration.

In a prospective, randomised study in nasal and paranasal sinus polyposis, Zhang (1993) showed longer intervals before recurrence following laser surgery compared to traditional polypectomy. Over the observation period of 18-30 months, the rate of recurrence in patients after Nd:YAG laser polypectomy was 46.6%, while the incidence after conventional polypectomy was significantly higher (66.6%, $p < 0.01$).

It is difficult to draw the conclusion that there is a decrease in the incidence and rate of recurrence of polypi following laser usage. The natural history of the disease is extremely variable. There are as many endogenous and exogenous factors as there are intra- and interindividual variations with respect to the localisation, size, and morphology of polypi and adjacent anatomical structures. The extent of surgical clearance by each method, and the continuing use of topical corticosteroid, are other variable factors.

Therefore, the value of laser technology in the management of polypi would seem to be twofold. In primary cases, the bulk can be reduced nearly bloodlessly so that the anatomical landmarks are clearly displayed (Fig. 5). Subsequent removal is then a much more controlled affair. Outpatient-based laser management of any early recurrence noted at the time of a regular review is yet another advantage. Early clearance also helps to break the vicious cycle by improving ventilation and drainage of ethmoidal areas.

Quoting Selkin (1985) and Levine (1989a,b, 1991, 1997), Johnson (1990) listed some advantages of the KTP laser-assisted technique, such as accurate removal of tissue with little direct contact, and the facility to minimise bleeding by coagulation. This article also mentions a possible beneficial effect on the incidence of recurrence.

3.3. Other applications

Steiner (1989), using argon laser found endoscopic laser surgery clearly superior to conventional techniques in removing residual peritubal adenoid tissue, stenosis, and cysts, and related this observation to the "non-contanct" application of the laser and absence of intraoperative bleeding.

In 1984, Lenz recommended the argon laser for the management of bleeding from the area of Kiesselbach in chronic recurrent nasal bleeding.

Soh (1996) and Ducic *et al.* (1995) advocate the use of the Nd:YAG and the KTP (532 nm) lasers in the management of coagulopathy and haemorrhagic diathesis.

In one authors' (JUGH *et al.*) department the Nd:YAG laser has now been replaced by the more compact and maintenance-free diode laser. The depth of penetration of the diode laser is much less than that of the Nd:YAG laser.

3.4. Complications from endonasal laser applications

Extremely low rates of complications are reported in many papers in the literature following endonasal laser usage.

Warnick-Brown and Marks (1987) reported high rates of complications in traditional submucous turbinectomy, such as dryness of the nasal mucosa, epistaxis, and cacosmia in 43%, 10%, and 12% of patients, respectively. In contrast, the present author (JUGH) observed no complications following laser turbinate reduction, apart from one case of secondary bleeding which was quickly controlled with nasal packing.

In a total of 250 patients treated with the CO_2 laser for various indications, Selkin (1985) found 11 cases with intra- or postoperative haemorrhage, two cases of septal perforation, and one of rhinitis sicca. Recurrence of nasal obstruction was observed in four cases, and thermal damage of the nasal skin in two other patients.

Soh (1996) reported a low incidence of bleeding during laser turbinectomy and cauterisation, and found lack of the need to pack the nose an added advantage.

4. Laser requirements in nasal surgery

Although almost any fibre-transmitted laser energy can be used for nasal surgery, some lasers perform better than others, depending on the following criteria.

4.1. Fibre transmission

The nasal cavity is dark and naturally crowded with anatomical structures. The presence of pathology further compromises the space with regard to instrumentation. There may be additional incidental obstructions, such as a deviated nasal septum. Finally, infant and child noses are rather small and the space is very limited. Delivery of laser energy by fibre transmission offers a distinct advantage. The fibres are extremely small, ranging from 200-1000 µm in diameter (Fig. 6). A dedicated channel could be incorporated into a slim multifunctional application sheath (Storz) to carry the fibre, endoscope, and a smoke evacuation channel (Figs. 7 and 8). Another possibility – which is cheaper but somewhat more cumbersome – is to guide the fibre within, or adjacent to, the suction cannula (Fig. 9). Thus, the laser energy can be taken right to the target tissue almost anywhere in the nasal cavity.

When using an optical fibre to deliver the laser energy, the following considerations apply:

Positioning of the fibre tip

Fibre-guided laser radiation can be transmitted to the target tissue by three different methods. In contact applications, the fibre tip rests on the target tissue. In the non-contact or near-contact methods, the fibre tip is some distance away from the target tissue. In interstitial applications of the energy, the fibre is introduced within the substance of the tissue prior to application of the energy. The tissue effects and the surgical outcome will be extensively governed by the method of application, and particular care should be taken that one method of application is not substituted by another without good reason!

The tissue effects are somewhat more unpredictable in the non-contact and interstitial methods of energy application. In the non-contact mode, the laser power density, which represents the determining factor for surgical efficiency, decreases exponentially as the distance from the surface increases. Moreover, it is not possible to keep the distance between the fibre tip and the target tissue absolutely constant. Thus, the tissue effects will be variable for the same setting and wavelength in the hands of the operator at any point in time.

In interstitial applications, the tissue effects are not visible to the surgeon. Moreover, any spread of energy to vital tissues in the vicinity will also remain undetected at the time of application. Therefore, the interstitial method should only be used by an experienced surgeon and in selected anatomical areas.

Beam parameters

The tissue effects are further modified by varying the beam parameters for a given laser. The following 'rule of thumb' is useful for any fibre-delivered laser energy:

- for a given level of total energy, the rate of vaporisation can be increased by increasing the power;
- for a given level of total energy, the amout of coagulation can be increased by decreasing the power;
- for a given power setting, higher density can be achieved by reducing the spot size. High power density results in vaporisation, with only a small amount of energy being conducted into the tissue. Coagulation is less, and therefore, haemostasis will be poor.

Pre-carbonisation of the fibre tip

The high optical penetration depth of the Nd:YAG laser produces a relatively large coagulation zone because the scattering rate of photons is many times higher than the absorption. The vaporisation zone is correspondingly shallow. Pre-carbonisation of the fibre tip results in maximum absorption of the energy by the char covering the tip. When the beam is activated, the temperature of the carbonised tip rises to between 300 and 600°C. This allows the local vaporisation process to take place in tissues in the close proximity, and reduces scatter. Pre-carbonisation of the tip is carried out by firing the laser energy onto a drop of the patient's blood, or onto the ink of a surgical marker on a wooden spatula. The carbonised tip absorbs 90-95% of the irradiated photons when the laser energy is subsequently used for surgery.

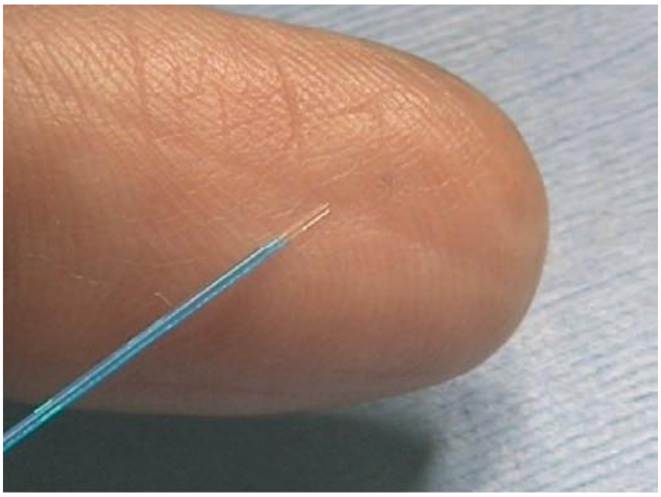

Fig. 6. Silica optical fibre with an external diameter of 365 µm, used to deliver Ho:YAG energy to target tissue.

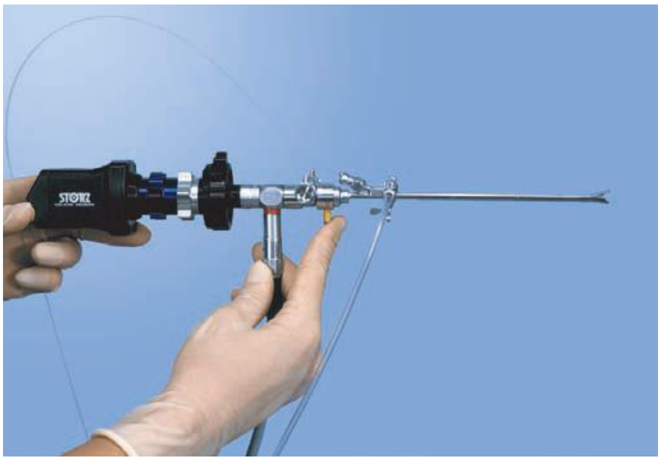

Fig. 7. Laser endoscopic application sheath (Storz) with an Albarran lever for functional endoscopic endonasal laser surgery.

Tactile feedback

The fibre tip can be used to assess the consistency of the tissue by gently probing it. This tactile feedback can differentiate between the soft feel of a polypoid tissue and the firm feel of a scar or a bony or cartilaginous tissue.

Optical laser fibre delivery

Manufacturers of various lasers supply suitable fibres for nasal applications. Their diameters range from 200-1000 µm. Since the spot size of the beam is directly proportional to the diameter of the fibre, the 1000-µm fibre has the largest spot size. Thus, for a given setting, a fibre with

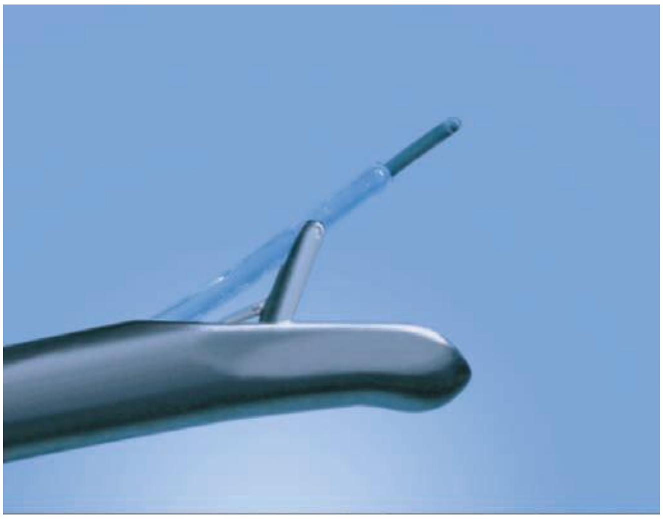

Fig. 8. Close-up of the Albarran lever. This device enables the surgeon to point exactly onto the surgical target without moving the entire instrument in the narrow nasal cavity.

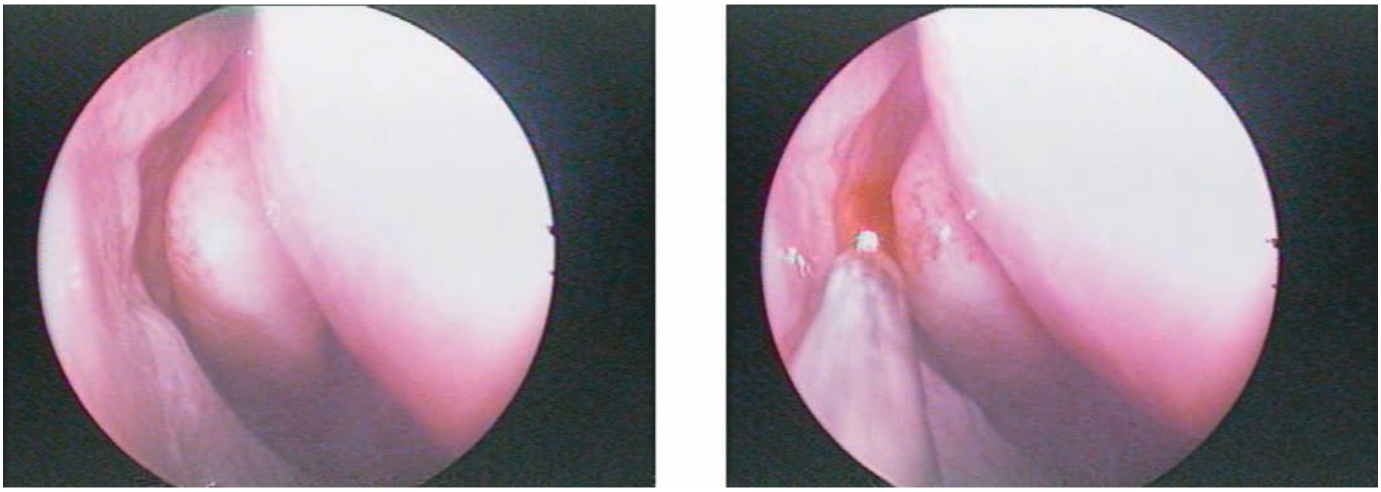

Fig. 9. The fibre can be guided to the target tissue by passing it within (illustrated) or adjacent to the suction cannula.

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larger diameter will deliver less energy density to the target in the contact or near-contact mode. Furthermore, the beam exiting from the tip of the fibre is not collimated; instead, it is a divergent beam. The angle of divergence is some 15-30°. Withdrawing the tip of the fibre away from the tissue will increase the spot size and decrease the energy density incident on the target tissue.

Excessive charred tissue may stick to the tip of the fibre. The energy is then wasted in heating up the charred tissue, with less going to the target. The charred tissue from the tip should be wiped away with a wet swab. Furthermore, if the energy emerging at the tip is less than anticipated, the firing should be discontinued immediately. The whole fibre and the coupler at the proximal end of the fibre should be examined for any damage and leakages.

The tip as well as the coating and cladding will deteriorate with prolonged use and repeated sterilisation. It is possible to freshen the tip by cleaving the fibre and removing the cladding. It is necessary to ensure that the emerging beam from a freshly cleaved fibre is perfectly circular with sharp edges, and without any distortion of the HeNe beam. A distorted beam will not deliver full power to the target, and also the energy may spread to the tissue adjacent to the target (Fig. 10A,B). It is worth noting that if a fibre marketed for single use is cleaved and reused on another patient, the manufacturer's warranty is nullified.

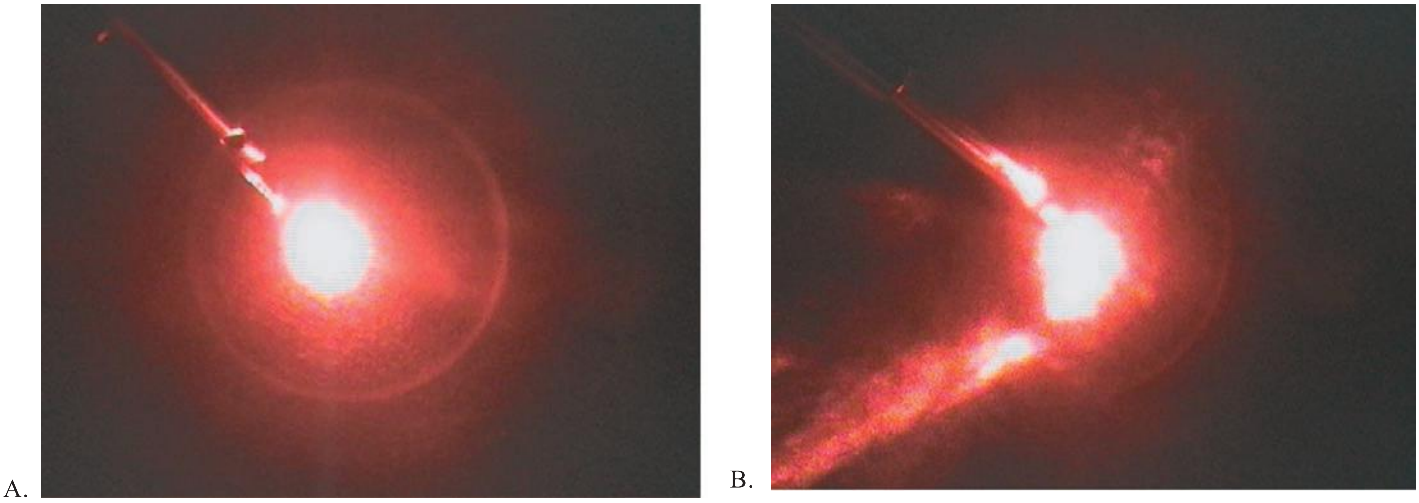
The choice of fibre diameter depends on the desired tissue effect and the size of the available working channel of the endoscope. The relationship between fibre-core diameter and tissue effect should be taken into consideration when choosing parameters.

4.2. Delivery of laser energy to the target tissue

It is feasible to deliver the energy via the fibre by simply taping it to the endoscope. However, this method of delivery is extremely inconvenient, and gives the surgeon much less control over the procedure. Therefore, it is advisable to use the dedicated instrumentation described later.

4.3. Mode of application of laser energy

Some lasers (Nd:YAG, diode) can be used in either the 'chopped' or 'continuous' mode. In the chopped mode, the laser beam is produced continuously, but its delivery is interrupted by means of a simple shutter mechanism integrated into the laser unit. Laser on time (exposure time) and off time (no-exposure time) are preselected. In contrast, in the continuous mode, the laser beam is guided from the laser unit to the target area with no interruptions. The application of energy in chopped mode reduces collateral damage.



A. B.

Fig. 10. The emerging beam from freshly cleaved fibre should be perfectly circular with sharp edges and without any distortion of the HeNe beam (A). Distorted beam (B) will not deliver full power to the target and also the energy may spread to the tissue adjacent to the target.

4.4. Intraoperative haemostasis

The mucosal lining is normally very vascular with sinusoidal vessels in the submucosa. This vascularity is particularly noticeable in cases of rhinitis medicamentosa. Hereditary telangiectatic lesions bleed profusely. As with conventional surgery, preliminary decongestion of the mucosa helps to minimise intraoperative bleeding. A laser with adequate coagulation properties provides intraoperative haemostasis and increases precision of the surgical procedure. It also obviates any need for postoperative packing, which is uncomfortable for most patients, and also entails an inpatient stay.

4.5. Ablation of bone

Ablation of bone in the management of middle meatus pathology and for dacryocystorhinostomy (DCR) requires high-power lasers. Low-power levels produce charring rather than vaporisation. Continuing strikes on charred tissue result in an increase in the temperature of the charring well beyond the vaporising temperature and the charring starts to flare. The high temperature reached in the charred tissue is conducted deep into and beyond the target tissue. Inefficient ablation of tissues in the vicinity of important structures such as the optic nerve poses a potential hazard.

Generally, therefore, it is advisable to use high power settings with short exposure times for ablating bone or cartilage. High energy levels can be obtained by using small-diameter fibres with energy applied in the chopped mode. The laser parameters for various lasers are described later.

4.6. Depth of penetration

Deep penetration leads to gross destruction of the tissue due to the conduction and scatter of laser energy beyond the intended target. Damage to the orbital contents (orbital fat, extraocular muscles and optic nerve) and the infra-orbited branch of the trigeminal nerve are serious potential hazards, resulting from deep penetration of the laser energy. The CO_2 laser has a shallow depth of penetration. However, this property makes it a poor coagulator as most of its energy is efficiently absorbed at the surface. The optimum laser for endonasal surgery should have a shallow depth of penetration to protect the vital tissues, but, at the same time, have enough energy to cause superficial and lateral coagulation in order to achieve intraoperative haemostasis. The Ho:YAG laser performs well in this respect as it is well absorbed by the mucosa, and, at the same time, its adequate pulse energy provides good coagulation and haemostasis.

4.7. Evacuation of smoke and debris

In order to maintain progress during the procedure, it is necessary to remove smoke from the operation site as soon as it is produced. Inadequate removal will deposit volatile combustion products on the lens. It is then necessary to suspend the laser application and to wipe the lens clean with betadine on a piece of gauze, which is placed in the proximity of the nose.

5. Which laser

5.1. CO_2 laser

Although one of the very first lasers to be introduced into otolaryngology, the CO_2 laser is not commonly used in endonasal laser surgery for a number of reasons.

Lack of fibre transmissibility
A huge drawback of early CO_2 technology was the lack of fibre transmissibility. The energy could not be transmitted to the target tissue unless it was in direct view, and endoscopically guided nasal surgery was not possible. However, some workers were able to use the CO_2 laser in the free-beam mode for some surgical procedures on sites limited to the anterior third of the nasal fossa, accessed by using Thudicum or Killian's speculum. The beam was delivered coaxially with a micromanipulator attached to the operating microscope. Reduction of the enlarged anterior end of the inferior turbinate and removal of synechiae between the septum and the turbinate were easily achieved. However, inadvertent tangential or direct alar strikes are always a possibility and lead to unsightly scarring. This is particularly relevant, since there is no correlation between the spot size of the HeNe and the CO_2 beam. The alar skin can be protected by using a large-sized aural specu-

lum. A small suction cannula soldered to the inside of the speculum effectively removes the smoke away from the surgical site.

Limitations of hollow wave-guides

In recent years, hollow wave-guides of varying diameters have become available for the application of the CO_2 laser in endonasal surgery. These tube-shaped applicator units contain a reflective internal coating and are capable of transporting the beam on a straight, curved, or slightly bent path.

The passage of the laser beam down the hollow wave-guides results in partial absorption of the energy by the material in the internal wall of the wave-guides. For a given setting, the beam delivered via a wave-guide is less powerful than a direct free beam. Furthermore, the absorbed energy is converted into heat. Therefore, it is necessary to operate the wave-guides with air insufflation in order to provide cooling.

Increasing the power setting can compensate for the loss of energy in the line. However, as the power setting is increased, the likelihood of heating up the outer and internal walls also increases. Eventually, the applicator may suffer considerable damage and need replacement. Some hollow wave-guides are equipped with a diamond tip which minimises the damage, provided the hollow wave-guide is also equipped with gas cooling.

Recently, newer hollow waveguides, 'OmniGuide BeamPath' and 'Fibre-Lase' have been marketed, and are said to overcome some of the disadvantages of the old hollow waveguide technology. For further reading, see Chapter 59.

Poor coagulation

The pathology in turbinate hypertrophy is usually in the submucosa. The CO_2 laser is predominantly absorbed by water in the mucosa, with very little spread of energy into the submucosa. The coagulation effect is therefore poor.

Poor haemostasis

In order to achieve intraoperative haemostasis, the operator may use the beam in the defocused mode. The defocused mode results in greater irradiation of the superficial mucociliary layer affecting the intrinsic transport mechanism, something that is not desirable. In theory, therefore, CO_2 laser action is inferior to that of other lasers.

Due to the relatively poor coagulating power of the CO_2 laser beam, there may be some oozing. Insufflating the cooling gas on a bleeding tissue may cause splattering of blood droplets. The spattered blood soils the lens of the endoscope, which needs frequent cleaning.

Increased risk of synechiae formation

The inferior nasal fossa affected by pathology is not usually wide enough to permit passage of the CO_2 laser wave-guide, unless the medial surface of the turbinate is first vaporised. This limitation may predispose to the increased incidence of synechiae formation between the inferior turbinate and the septum.

5.2. KTP/532 laser

The continuing development of laser technology in the 1980s and 1990s produced a number of wavelengths, which were eminently suitable for nasal applications. The KTP/532 wavelength (KTP) is fibre transmissible. It has a high affinity of absorption for pigmented tissue, such as haemoglobin. The energy conducted into the tissue is well absorbed by the sinusoidal blood vessels of the turbinate and results in a coagulation zone with very little intraoperative bleeding. The irreversible tissue damage suffered by the coagulated zone causes significant postoperative inflammatory oedema and crust formation. However, the incidence of secondary haemorrhage is negligible. Therefore, the KTP laser has been used extensively in nasal surgery and has rightly become the second laser of choice in otolaryngology, after the CO_2 laser. Its place has been further secured by increasing applications in otological procedures, which are described elsewhere.

The KTP laser has adequate power for ablation of the bony framework of the MMC. It has also been used effectively for DCR. However, in the latter procedure, the bone can sometimes be very thick, resulting in charring rather than ablation. The newly introduced Star Pulse mode has addressed this issue. It delivers a very useful ablative power for bone work during DCR.

5.3. Argon ion laser

The argon laser is a gas laser characterised by its strong selective absorption by melanin and haemoglobin at 488 nm (blue) and 514 nm (green), respectively. The laser can be used not only in the continuous-wave and chopped modes, but also in a short-pulse mode. The beam can be coupled to a very small fibre with a diameter of only 50 µm. This ensures high power density and an extremely precise technique. However, its wider use was somewhat restricted due to its poor efficiency and high capital and revenue costs. It is common to use flexible quartz fibres with core diameters of 100, 200 or 400 µm to transmit the light of the argon ion laser. The external diameter of these fibres is somewhat smaller than those used in Nd:YAG and diode laser surgery. Consequently, the argon ion laser is easy to combine with miniature and micro-endoscopes. In addition, the thin fibres allow slightly greater flexibility and resist fracture.

5.4. Ho:YAG laser

The Ho:YAG laser delivers high, fibre transmissible, pulsed energy. The wavelength 2100 µm is strongly absorbed by water, and the depth of coagulation zone is therefore shallow. The laser strike results in immediate and rapid heating of the tissue, which suffers vaporisation. The remaining energy expands the tissue, which then explodes, splattering fragments in the direction of the incident beam. Mechanical effects on the underlying tissues, such as micro-fractures, have also been observed. This process is oligothermal, but not completely athermal (*i.e.*, without the effects of heat). The lesion thus produced shows a small margin of coagulation when a shorter laser pulse is used. The high energy used on the bone reduces it to ash rather than char and is thus especially useful for ablation during DCR.

A serious disadvantage of the Ho:YAG laser is the splattering of the tissue, which causes soiling of the endoscope lens, requiring frequent cleaning. The splattering can be addressed in two ways: using a high pulse rate can reduce the amount of splattering; and, using an operating microscope instead of the endoscope provides clean access and visualisation of the tissue. The 300-mm optics are a considerable distance away from the operating site and thus remain splatter-free. In contrast to the endoscope, the microscope also provides magnification, which is useful for precision surgery. On the other hand, the microscope is bulky to manoeuvre and its use adds to the operating time. Access to the lateral wall is somewhat limited when using the microscope. It is also more difficult to use in patients who are undergoing surgery under local anaesthetic.

The Ho:YAG laser is an efficient but expensive system, only suitable for experienced surgeons working with endoscopic or microscopic techniques, who wish to use this laser as an additional instrument in functional sinus surgery. The availability of this laser for otolaryngologists will increase as it is being increasingly bought by genito-urinary (GU) departments for the management of benign prostate hypertrophy and renal stones. In one author's (VO) experience, this laser has proved extremely useful for a variety of nasal conditions for soft as well as hard tissue ablation. If available to the otolaryngologist, every effort should be made to acquire proficiency in its use for nasal pathology as well as for laser-assisted uvulopalatoplasty (LAUP).

5.5. Diode lasers

Diode lasers have the simplest and most maintenance-free laser technology. The photons are produced by an electrical current. Several diodes are arranged in arrays to produce the output power required for medical applications. Owing to their high efficiency, these lasers do not need bulky power units or cooling systems. Small, portable versions, barely larger than a high frequency (HF) surgery unit, are available. Thus, the equipment is relatively cheap, extremely portable, and comparatively maintenance-free.

When considering the diode laser, it is necessary to appreciate that the various commercially available models emit at different frequencies, ranging from 805, 810, and 820, up to 980 nm. The 805-nm beam is strongly absorbed by the haemoglobin in the blood, regardless of its state of oxygenation. Photons with a wavelength of between 940 and 980 nm are also absorbed by haemoglobin, but in addition, they are also well absorbed by water. Since the absorption of any laser energy is primarily dependent on its wavelength, it is not surprising that the tissue interaction will vary from one diode laser to another. Thus, when diode application is considered, it is necessary to state the specific wavelength emitted by that particular laser.

The mode of transfer of energy is similar to that of the Nd:YAG laser, but somewhat different from others. The fibre tip is initially carbonised by striking a wooden spatula in the contact mode. Thus, the tip is covered with a thin layer of char.

The carbon layer absorbs the laser photons efficiently. The temperature of the carbon layer rises rapidly to over 300°C. The high temperature allows a high power density for use in the chopped mode to vaporise both soft and hard tissues, with only a small amount of collateral damage to the surrounding non-target tissues.

Due to the somewhat shallower penetration of the diode laser photons, it is not necessary to use high power settings to produce the coagulation of tissue. The coagulation effect can be produced in the continuous mode at lower laser powers in a contact (2–5W) or non-contact (2–15W) procedure.

The therapeutic options available with this system are extensive. The laser can be used both in the continuous-wave and chopped mode. This allows the surgeon to achieve a variable combination of tissue interaction between the coagulation and vaporisation of endonasal and paranasal tissues. However, the applicability of this laser is not limited to the soft tissues. Even bony and cartilaginous parts of the nasal septum and ethmoid can be successfully and safely managed with it.

The 'medilas D' diode laser (Dornier) produces much higher laser power, *i.e.*, between 20 and 80 W in the chopped mode. Laser exposure times are selectable over a wide range, between 0.01 and 1.0 seconds, and are interrupted by intervals of 0.1–1.0 seconds. For vaporisation of cartilaginous and bony tissues, such as the septum, concha bullosa, choanal atresia, and medial maxillary sinus wall, it is essential to apply this laser for short exposure times at high power settings with long intervals between exposures, in order to deliberately minimise the coagulating effect on the neighbouring tissues.

Activation of the beam in the contact mode has certain disadvantages. Since the fibre tip in contact with the tissue is actively energised, it immediately ablates the tissue. The thermal effect can continue to penetrate deeply, unless the fibre tip is moved away to the virgin tissue. This 'reaction time' on the part of the surgeon can be critical if the ablation is being carried out in the vicinity of a vital structure. A better and safer way is to activate the beam in the vicinity of the tissue, and then to work on the tissue as required. The advice from some quarters of, "On, on the tissue; off, off the tissue" seems inappropriate.

5.6. Nd:YAG laser

The Nd:YAG laser is also fibre transmissible. However, it is poorly absorbed by most chromophores and, therefore, exhibits a high degree of scatter. The depth of penetration, and therefore, the depth of thermal damage, can be of several millimetres, leading to gross tissue loss. However, for some lesions, such as the ablation of malignant tissue, this effect of the Nd:YAG can be regarded as therapeutic. Thus, for bulk reduction of tissue by vaporisation, the Nd:YAG laser is applied at high power (35-50W) in the chopped mode with relatively short exposure times in the range of 0.1-0.2 seconds, with pauses in the ratio of at least double to four times the exposure time. In these conditions, a power density of 12,000-40,000 W/cm^2 can be achieved.

Coagulation of the tumefacient tissue can be undertaken with an Nd:YAG, to promote scarring predominantly in the submucous layer. The power setting is dictated by the mode of application, either in the contact or non-contact position. In the contact position and in the continuous mode, the power setting is low (3–8W). In the non-contact position, the power setting is high (15-20W), and so is the scatter in the tissue. It is necessary to appreciate that, in the contact position, the irradiance at a given power level is only, say, 1000-6400 W/cm^2, whereas, at the same setting, in the non-contact position, it can reach 5300-16,000 W/cm^2.

6. Instrumentation for endonasal laser surgery

As in laser surgical applications elsewhere in the body, an important aspect of laser usage in endonasal applications is the precision with which surgical procedure can be carried out. This advantage will be undermined if a proper view is obstructed due to the smoke and vapour produced as a result of tissue ablation. Precision surgery will also not be possible if the view of the target and the surrounding tissue is inadequate. The instrumentation for endonasal laser surgery is based on these two basic considerations.

Many procedures in the anterior part of the nose do not require any specific instruments. Standard nasal sets are adequate for most procedures involving the anterior third or so of the nasal cavity. However, it is obvious that, for surgery in the deeper part of the nose, the endoscope, the laser fibre, and the suction cannula are required. This instrumentation severely encroaches upon the limited space available, which may be further compromised due to the presence of pathology. The laser delivery systems therefore need to be as slim as possible.

6.1. Rigid endoscopes

Rigid endoscopes are fitted with high-quality rod lens optics and offer the highest resolution and, thus, afford a sharp and detailed view, especially when working with a digital or analogue imaging camera. In addition, rigid endoscopes are slightly easier to position inside the nose, due to their better handling properties. The endoscope rests securely (without slipping) in the hand of the surgeon, who is usually familiar with the instrument from previous experience in conventional endoscopic sinus surgery.

The detailed view of the operation site provided by a 0° wide-angle telescope is slightly inferior, because a sharp image is only produced if the distance to the object is at least 2 mm or more. However, these telescopes allow for a distortion-free visualisation of small target areas.

Rigid endoscopic instruments are based on a prototype developed by Rudert. The design of endoscopes and its dedicated sheath were later miniaturised by Hopf (Hopf *et al.*, 1988), and modified with an additional channel to hold the laser fibre. Fitted with a smoke evacuation facility and integrated fibre channel, the handle is oval-shaped and has a maximal outer diameter of 4.2 mm with and 3.7 mm without the steering mechanism. Handles can be attached to various angled endoscopes with diameters of 1.9-2.7 mm.

The sophisticated multi-channel laser application systems offered by various manufacturers are not only highly efficient, but also offer superior intraoperative safety and manoeuvrability. The ability to move away from or closer to the target tissue provides better control between contact and non-contact laser techniques, and influences the intraoperative bleeding and depth of coagulation.

The fibre-guiding groove of the working channel is equipped with an Albarran lever which allows the fibre to be steered by up to 50°. The ability to steer the fibre tip is a clear advantage, making it easier to place it on the surface of the target tissue, particularly in areas not in direct vision and straightline access. Thus, the tip can be steadied on the tissue with minimal slipping in the contact position. If the tip slips, the application of the laser energy will be in non-contact position, thus altering the vaporisation and coagulation effect, with immediate and long-term adverse surgical outcomes.

The relatively large external diameter of the assembled instrument sheath limits the application in confined anatomical areas. Consequently, in collaboration with the authors, Storz developed smaller oval endoscope sheaths with ball-shaped tips matching the internal lumen of the nasal cavity. In these instruments, the fibre, telescope, and suction channels are arranged in a concentric fashion. These telescopes are modular and interchangeable, and provide for both suction and a laser fibre channel.

Endoscopes with smaller external diameters are much more comfortable for patients, particularly children, treated under local anaesthesia without sedation. The narrower instruments can also be used in children from nine years of age upwards. Newer narrower laser endoscopes with improved tips have a ball-shaped end, reducing the instrumentation trauma.

As a minor disadvantage, it must be mentioned that the smaller lumen channels of the narrower endoscopes do not evacuate smoke very efficiently. Since endonasal surgery is performed in a moisture-saturated environment, obstruction by wet smoke particles is certainly possible with these instruments. Smoke particles may also adhere to the telescope lens during surgery, in which case the procedure must be interrupted to clean the lens, preferably with a cotton carrier soaked in a detergent and anti-fog solution.

The suction channel of the laser application sheath can easily be disassembled into an external and internal sheath. After disassembly, the components should be soaked in a cleaning solution, and then cleaned with a set of small brushes. Both parts are then subjected to liquid, gas, or autoclave sterilisation.

6.2. Flexible endoscopes

Flexible endoscopes are extremely useful for laser surgery in the paranasal sinuses. Flexible and active tip-controllable nasopharyngoscopes, and tracheobronchoscopes for children, are equipped with a working channel in conjunction with a suction facility. The outer diameter ranges between 2.5 and 3.5 mm. The use of flexible endoscopes is rather difficult and requires a great deal of experience. Due to their flexibility, there is an inherent instability which makes it difficult to place the tip accurately onto the target and maintain it there during laser exposure. Even if positioned properly, each movement of the surgeon's hand is immediately transmitted to the flabby mid part of the endoscope tube and its distal end, resulting in displacement. Therefore, for clinical applications, it has often proved useful to pass part of the length of the flexible endoscope through a rigid guiding handle in order to keep it in its proper position, thus providing a support for the flexible instrument *en route* through the main nasal cavity, making it semi-flexible. Endoscope manufacturers are still working on this specification, and prototypes are now available.

The flexible laser endoscope is particularly useful in the following situations:

- In revision cases of FESS, previous conservative surgery may obstruct the anterior ethmoid, nasofrontal recess, posterior ethmoid, and sphenoid area. These areas can be accessed even in a tight situation with a flexible endoscope, if the slim rigid multifunctional laser application sheath fails to reach the surgical target.
- The flexible endoscope is also particularly useful in cases in which there is a large and extended middle concha, which effectively shuts off the middle meatus (Fig. 11).
- Likewise, where access to the agger nasi and uncinate process is limited due to cicatricial lateralisation and scarification of the middle concha following moderate conchotomy carried out with traditional FESS, the flexible endoscope is extremely useful.
- In cases where there is a substantial spur and the patient refuses to undergo the necessary surgical correction, it is often extremely difficult to perform an operation on the posterior parts of the nasal cavity, the posterior ethmoid, the sphenoid region and the nasopharynx, when using rigid instruments only. Flexible endoscopes are useful in such cases.

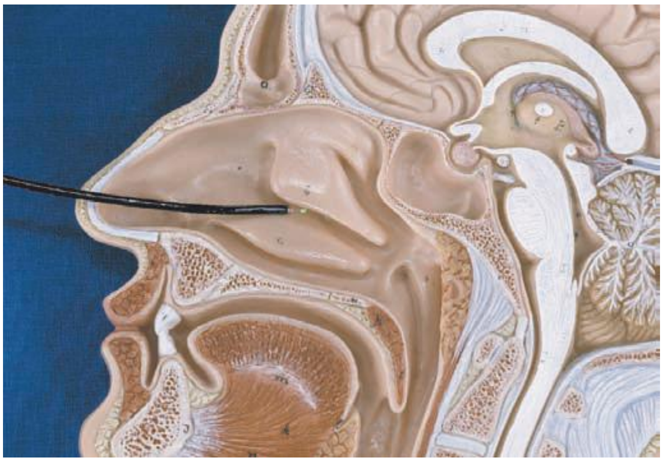


Fig. 11. Flexible endoscopes are extremely useful for laser surgery in the paranasal sinuses.

The detailed resolution of the visual image provided by the flexible endoscope is somewhat inferior and less brilliant, due to the optical properties of the fibre bundles containing wide-angle optics. In particular, if a micro-endoscope with gradient optics is used, the quality and visual image can be impaired by the visible occurrence of Moiré lines, as well as by the pointed appearance of the monitor image when a chip-camera system is used. This problem is solved in the new digital video system manufactured by Storz by means of a specially integrated electronic video-filter, which filters out the Moiré lines.

6.3. Micro-endoscopes

Much progress has been achieved in the field of minimally invasive diagnostics and therapeutic procedures with the introduction of flexible and actively controllable endoscopes. The outer diameter is 1.8 mm with an integrated working channel of 650 μm. This miniature endoscope allows passage into the paranasal sinuses via their natural or surgically widened orifices. This method is primarily used for working through the middle meatus in cases of previously operated ethmoidal cell systems, frontal and maxillary sinuses.

Although flexible endoscopes are very useful, the smaller the endoscope, the less the total visualised area available to the surgeon to gain a quick overview of the operation site.

6.4. Flushing endoscope

Despite the continuous removal of smoke and charred debris from the area close to the operating site, prolonged tissue vaporisation will smudge the endoscope lens with carbon, and reduce visibility. It is then necessary to withdraw the endoscope and clean the lens. Some manufacturers have devised an ingenious single unit, which has several separate channels to accommodate the endoscope, fibre channel, suction channel, and also a user-controlled flushing channel, which squirts saline onto the endoscope lens. To add further to the complexity of the device, a steering mechanism is incorporated at its distal end so that the fibre can be directed precisely at the target on the lateral wall of the nose! Due to the obvious lack of flexibility of the individual components in the unit and to the high costs involved, this highly sophisticated device has failed to gain in popularity.

6.5. Suction-fibre delivery handpiece

Laser surgery is associated with the production of smoke and charred tissue debris. Although lasers can seal blood vessels of a certain size, depending upon the wavelength used, some bleeding is inevitable. In the narrow confines of the nasal cavity, the instant removal of the by-products of laser surgery is necessary in order to maintain a clear view of the surgical site. These products also need to be channelled into a dedicated filtering device in order to maintain a pollution-free operating environment. For this purpose, a suction cannula is kept in the vicinity of the operating site.

A very simple solution for simultaneous suction and fibre delivery is to feed the fibre through the PVC suction tubing by puncturing it. The fibre is then advanced until it protrudes from the distal end of a metal suction cannula, such as the Zolner or Lempert's cannula. It is then used as required, and any smoke is removed by the suction. However, such an arrangement has certain disadvantages. Commonly used laser fibres have a diameter of 600 μm (KTP, diode) or 365 μm (Ho: YAG). These thin fibres lack rigidity and can easily bend and jump on the surface of the tissue.

When used separately, the operator needs to use one hand for the endoscope and the other for the cannula. A multifunction endoscopic laser application sheath can offer a single-handed operation and an excellent ease in use in various operation sites.

A possible alternative method is to combine the laser fibre cannula and the suction cannula into a single unit. This can easily be done by soldering two cannulae into one unit. The diameter of the fibre cannula is only slightly larger than that of the fibre. In this way, the fibre remains in place due to the friction against the inner wall of the channel. The distal end is suitably bent (by 15–20°) laterally towards the wall of the nose. The laser fibre is fed into the fibre channel and protrudes at the distal end by about 1 cm. The second channel connected to the dedicated filter unit is used to evacuate the smoke in the vicinity of the operating site.

While a simple two-channel cannula may be adequate for KTP and diode lasers, surgery with the Ho:YAG laser poses some unique problems due to its pulse delivery mode. With each strike of pulsed energy, there is gross disruption of the tissue. Strings of tissue debris are expelled and fly some distance from the operation site. The endoscope lens smudges after only a few strikes, and requires frequent cleaning. Oswal designed a specific instrument for use with the Ho:YAG laser. The 'Oswal suction fibre cannula' (J.B. Masters Ltd, Cleveleys, Lancashire, UK) has two suction channels and one fibre channel encompassed within a single tube with an overall diameter of 4 mm (Fig. 12). Its use is demonstrated in Figure 13A,B,C. The tip of the fibre is placed exactly opposite the aperture in the extended suction cannula. The removal of tissue debris is instantaneous. The blunt extended end of the suction cannula also acts as a probe and a guide, thus helping to direct the fibre and assess the progress of the surgery. A larger diameter fibre channel is also available to accommodate larger fibres. The proximal end has a ball-and-socket joint for connection to the suction tube. This ball-and-socket joint prevents transmission of the rotating movement of the suction cannula, necessary for vaporising various areas of the nose. This design minimises the tension on the surgeon's hand, and prolonged surgical procedures can be undertaken without strain.

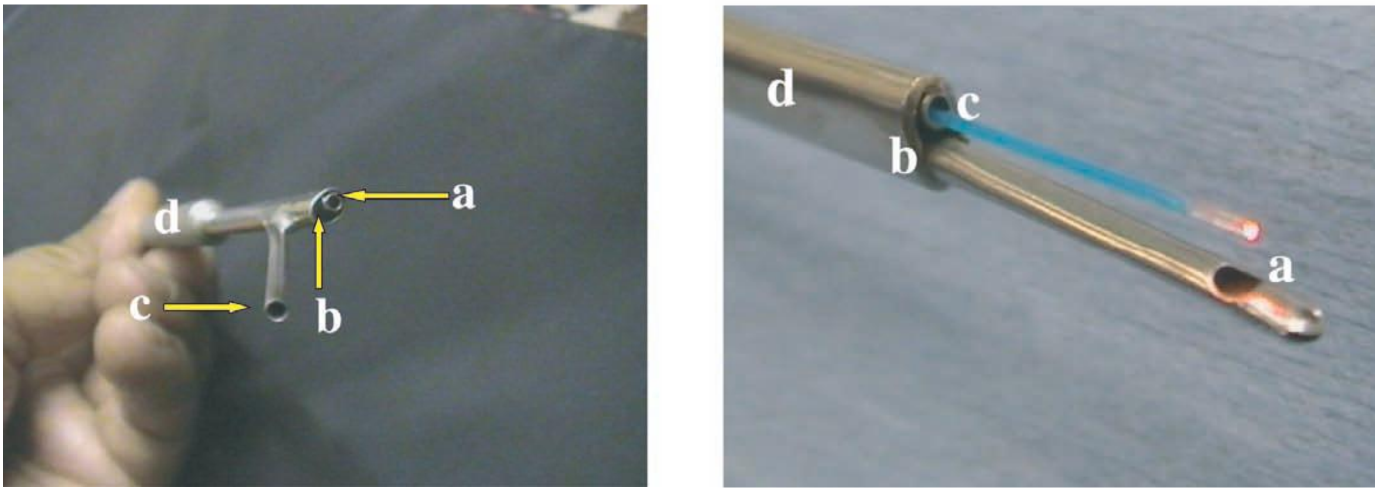


Fig. 12. The ‘Oswal suction fibre cannula’ (Manufacturers: J.B. Masters Ltd, Dorset Avenue, Cleveleys, Lancashire, FY5 2DB England) has two suction channels (a, b) and one fibre channel (c) encompassed within a single tube (d) with an overall diameter of just 4 mm.

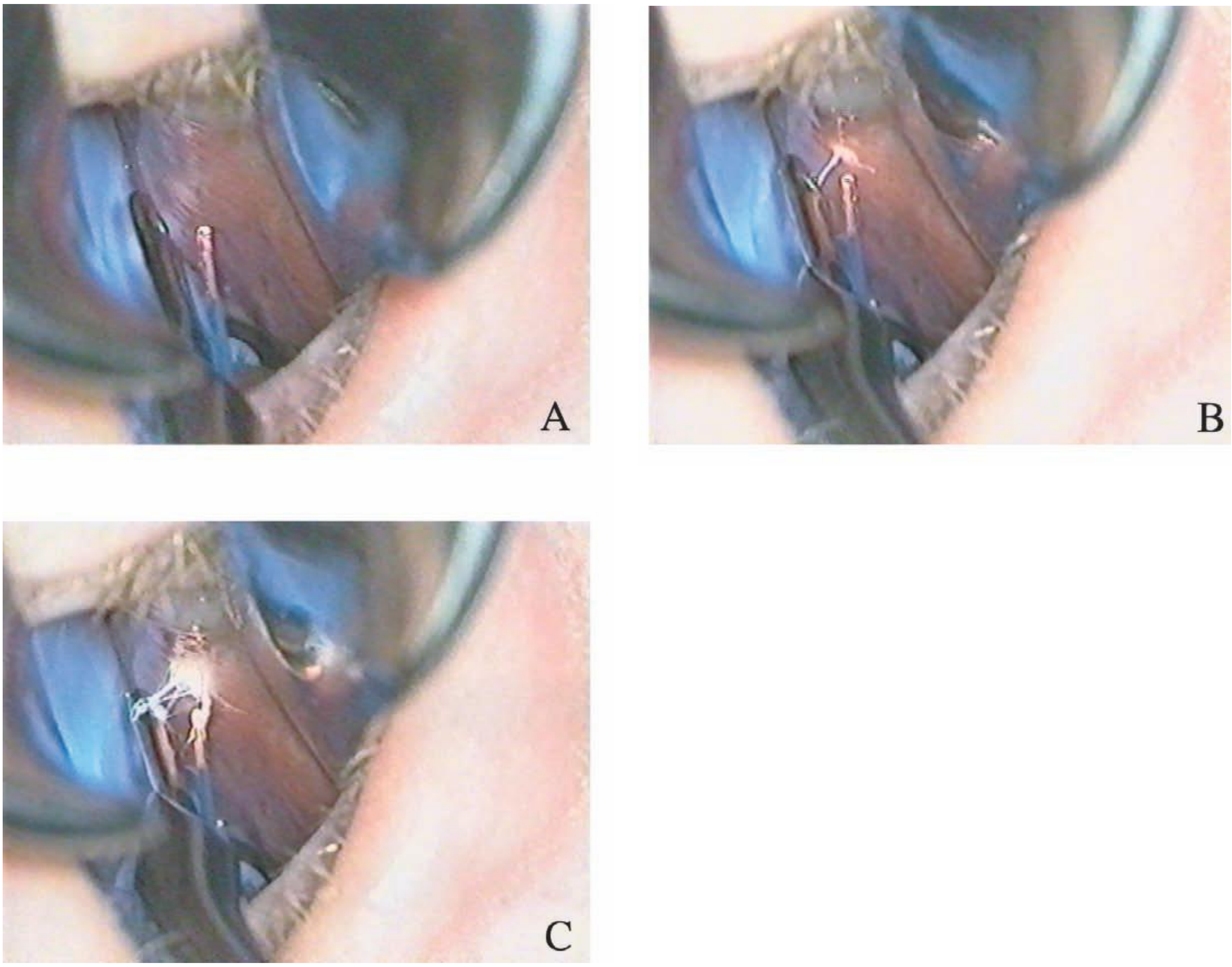


Fig. 13. (A) The ‘Oswal suction fibre cannula’. (B) The removal of the tissue debris is instantaneous. (C) The blunt extended end of the suction cannula also acts as a probe and a guide, thus helping to direct the fibre and ‘palpate’ the progress of the surgery.

7. Preoperative preparation

Careful planning regarding the operating time will enhance the procedure and gain patient confidence for subsequent procedures.

7.1. Protective eyewear

The patient, as well as the operating team, must wear wavelength-specific protective goggles that filter out the laser wavelength. There is no universal type of goggles available for all wavelengths, since it would have to be completely black!

7.2. Protection of non-target areas

For patients under general anaesthesia, suitable lubricant drops should be instilled into the eyes, and the eyelids taped and covered with wet swabs. The whole face should be covered with wet gauze, such as Gamgee.

7.3. Anaesthesia for endonasal laser applications

The use of local or general anaesthesia for endonasal laser surgery is dictated by personal and patient preferences, adequate office or day care facilities, current practice in conventional nasal procedures, etc. Unlike lasers in laryngeal surgery, there are no particular anaesthetic requirements for endonasal laser surgery under general anaesthesia. Precautions should be taken to cover the oral endotracheal tube with wet gauze, and to have it pushed well away from the nose. The oropharyngeal part of the tube may be in the close vicinity of the laser strikes in procedures undertaken in the nasopharynx. It should be protected with a wet swab inserted into the nasopharynx from the oral side.

7.4. Local anaesthesia

Endoscopically controlled laser surgery on pathological tissues of the nasal cavities and paranasal sinuses, as well as the nasopharynx, can be carried out as an outpatient using local anaesthesia (Fig. 14). Cotton wool soaked in naphazoline and tetracaine (4%) is placed in the nasal cavity for ten minutes. Then cotton wool held in a curved swab carrier is impregnated with lidocaine gel (5%) and placed on the pre-anaesthetised area. A local injection of 1-2% lidocaine solution with 1:200,000 epinephrine is rarely necessary, and then only in the anterior part of the inferior concha or the ethmoid.

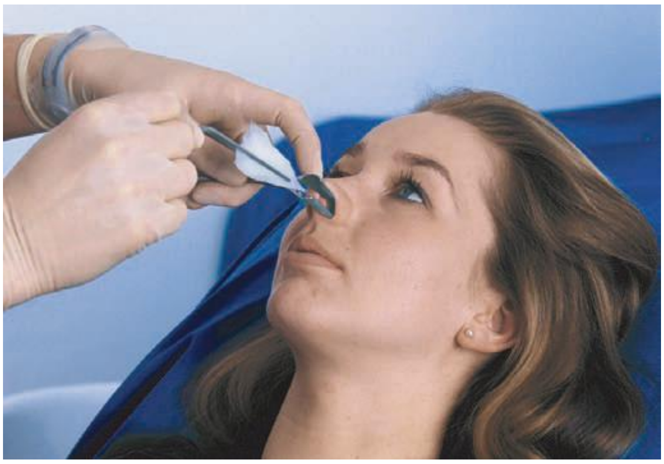


Fig. 14. For local anaesthesia and mucosal decongestion tetracaine/naphazoline-soaked cotton swabs are introduced for about 10 to 15 minutes prior to any FEELS procedure.

Normally no sedation of the patients is required. Depending on the operating room facilities, the laser procedure can be directly undertaken in the ENT examination chair, with the patient in a semi-supine or supine position with the head slightly inclined. The supine position is preferred by many somewhat anxious patients, especially when endonasal laser treatment is being carried out for the first time.

In revision surgery, local anaesthesia may not be adequate due to excessive scar tissue, and general anaesthesia is preferable. This is also true for patients with gross nasal polyposis and extensive disease in the paranasal sinuses.

The general anaesthetic method used for laser FESS is similar to that for cold instrument FESS, and does not call for any specific variations.

7.5. Insertion of the endoscope

Endonasal positioning of the instruments and the ideal positioning of the laser fibre should be carried out with calm, confident, and targeted handling of the procedure (Fig. 15). Apart from the mucosal anaesthesia, the sensitivity of the external nasal pyramid area and the deep sensitivity of all the facial soft tissues are not completely

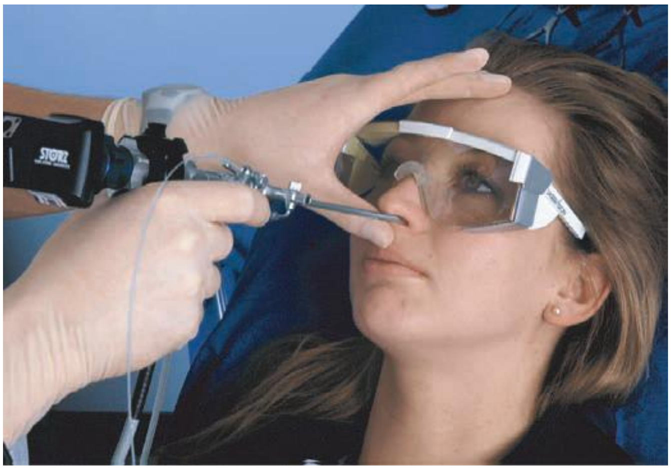


Fig. 15. The patient as well as the operating team must wear *wavelength-specific* protective goggles filtering out the laser wavelength. To prevent the nasal cavity from iatrogenic lesions caused by sudden movements, it is useful to put the instrument on the thumb of the left hand like a billiard cue.

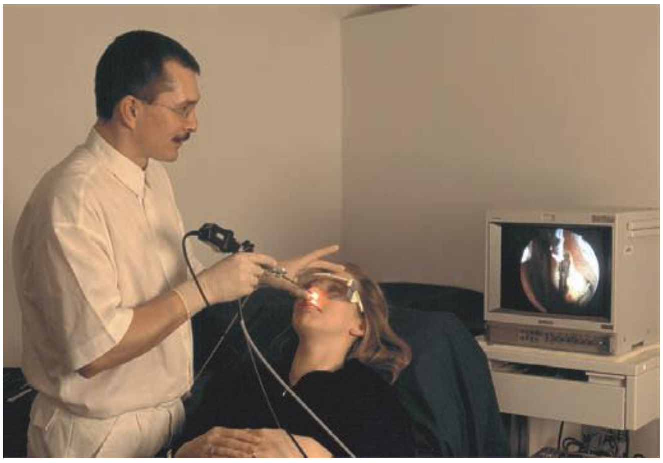


Fig. 16. The ideal position for the surgeon is similar to that adopted during conventional FESS procedures, *i.e.*, standing on the right side, beside the upper part of the patient's body

blocked. A painful experience during insertion of the instrument into the nares, nasal floor, and tip, can lead to an immediate cramp-like reaction by the patient when uncontrolled movements with the endoscope are carried out. The patient is then constantly anticipating further repeated painful experiences of this nature during the laser therapy. Such an initial experience will considerably reduce the theoretical treatment time available, as well as the compliance and 'stamina' of the patient.

7.6. Position of the operator

The ideal position for the surgeon is similar to that adopted during conventional FESS procedures, *i.e.*, standing on the right side, beside the upper part of the patient's body (Fig. 16). The operator should relax his arms close to the body, keeping them close and bent at the elbow. Right-handed operators usually hold the endoscope in the right hand, thus being gently supported by the facial soft tissues of the patient, if required. The left hand is exclusively used to undertake positioning, forward movement or withdrawal of the endoscope. Using a rigid endoscope with a shaft, the surgeon uses the left hand to operate the Albarran lever for raising the tip of the laser fibre. When using a flexible endoscope with a working channel, the right hand holds the endoscope and controls the lever for raising the entire distal tip of the endoscope.

7.7. Additional suction

When ablation of a large bulky tissue is planned, a considerable amount of smoke and tissue debris will be produced. For such cases, an additional evacuation catheter for the fumes should be inserted into the opposite main nasal cavity and advanced into the nasopharynx, so that the smoke is immediately evacuated out of the choanal area.

8. Access to the operating site

Access to the operation site will very much depend upon its position within the nose, the type of laser system (free beam/hollow wave guide versus fibre delivery) used, and the surgeon's preference.

8.1. Direct access

Sites within the anterior third of the nose can be accessed with Thudicum or Killian's speculum. However, when using the CO_2 laser in the free-beam mode, the alar skin may suffer inadvertent thermal damage. This will be seen as blanching, and may heal with an ugly scar. The spot size of the CO_2 beam in some systems is larger than the visible HeNe spot. A tangential strike on the target within the nose may result in part of the invisible CO_2 beam brushing against the alar skin and resulting in thermal damage. This may not be noticed at the time of surgery since the surgeon will only be following the visible HeNe beam within the nose.

The risk of damage can be minimised by using a large-sized (size 8) aural speculum inserted into the nostril and positioned to visualise the target. A small oval metal cannula can be soldered on the inside of the aural speculum, and attached to the suction unit. This will remove the smoke effectively, and thus obviate the need for other suction.

8.2. Endoscopic access

Almost all sites can be accessed with the use of a 2.5 mm, 0° or 25° endoscope, depending on the preference of the operator. There are also 1.9 mm endoscopes manufactured by Storz. 40° and 70° side-view endoscopes are particularly useful for exposure of the nasofrontal recess and for surgery of the MMC. The energy can be delivered via fibre transmission or using the CO_2 laser waveguide, as discussed in detail under 5.1. It is necessary to maintain a dry field by removing blood. This can be achieved by using the integrated suction-fibre unit. If the endoscope lens smudges, it can be cleaned with betadine on a swab placed in the vicinity of the nose for easy access by the surgeon.

8.3. Access with microscope

The microscope provides a magnified view of the target. By using a self-retaining Killian's speculum, the operator's hands are also free. However, positioning the microscope and manoeuvring it adds to the overall operating time. The endonasal access with microscope is usually appropriate for surgery under general anaesthesia.

The choice of instrumentation for access depends on individual preference, training, and expertise.

9. Monitor-controlled procedures

One of the present authors (JUGH) performs laser surgery routinely under video-endoscopic vision, observing the procedure on a monitor. This has four main advantages:

- The surgeon is not forced to peep through the 'keyhole-like' eyepiece of the endoscope in a darkened environment, as was required in the early days of FESS. Rather, even the affordable 1-Chip camera transmits a good quality image onto a monitor, and the enlarged picture provides a good 'on-line' biocular view of the operation site, combining the advantage of the enlargement of the surgical target with the possibility of inspecting and treating surgical targets hidden 'around the corner'.
- Using video-endoscopy, it is no longer mandatory for the surgeon to wear laser safety goggles in strictly intra-cavity applications with the Nd:YAG, diode, argon, and KTP lasers, in which the image is transmitted to a monitor through a glass fibre. In contrast, when the surgeon looks through the eyepiece of an endoscope (or microscope), his or her eyes must be protected from the laser beam by safety goggles or suitable filters attached to the eyepiece. The latter are rather expensive. The unprotected eye of the surgeon is mainly endangered if the light hits the metallic edge of the fibre channel and is scattered back to the eyepiece. But, in every procedure, with or without video-endoscopy, it is mandatory to ensure that the patient, under local anaesthesia, wears wavelength-specific and well-fitting eye protection, and closes his or her eyes during the laser procedure.
- Video-endoscopic vision allows the surgeon to perform the operation in a comfortable upright, standing position with no strain on his or her back or extremities.
- Any relevant findings or procedural steps can be documented simultaneously by means of video-endoscopy. Allowing the patient to watch the intervention while it is going on may actually increase patient compliance in some cases.

10. Risks and benefits to the patient

The risks and benefits to the patient from endonasal laser management of the pathology depend upon several factors. These are related to the characteristics of the laser energy, the laser wavelength used, the nature of the pathology, the surgical technique, and so on. The risks and benefits related to each surgical procedure are covered in the appropriate chapters, those peculiar to laser usage in the nose are covered in the following sections.

10.1. Thermal damage to the alar skin

Inadvertent thermal damage to the alar skin is a preventable complication and has been referred to above.

10.2. Septal perforation due to non-target thermal damage

In turbinate surgery using the Ho:YAG laser (but probably not with other lasers), the septal mucosa can become covered with hot charred tissue released from the operating site. Usually, this does not result in any permanent damage. However, excessive bilateral deposits may lead to thermal damage of the vessels of the perichondrium, leading to avascular necrosis and perforation. A silicon nasal splint can be used to protect the surface of the septum during laser surgery of the lateral wall of the nose. However, the operator should test its flammability for a particular wavelength and for different power settings.

10.3. Synechiae

Postoperative synechiae may result from devitalisation of the opposing mucosa due to hot debris or instrumentation trauma. The irreversible thermal damage is not apparent at the time of the surgical procedure. It results in a raw area, which may heal with synechiae to the adjoining tissue. Formation of gross synechiae in the middle meatus area should be avoided since these will influence the surgical outcome in, for example, FESS. Good postoperative nasal toilet for removing slough and crusting minimises the formation of synechiae.

10.4. Excessive bleeding

Bleeding can result from the operating site or due to instrumentation trauma to the mucosa, or both. The laser action is ineffective in the presence of gross active bleeding. In particular, the KTP and argon wavelengths are preferentially absorbed by blood, and therefore the energy received by the target would be negligible. Therefore, any bleeding must be minimised and controlled. In common with conventional nasal surgery, effective preoperative decongestion of the nasal mucosa is particularly useful in laser surgery. Between laser strikes, insertion of ribbon gauze impregnated with a suitable decongestant will control bleeding and will also remove charred tissue debris covering the surgical site.

10.5. Lack of sufficient energy

If the energy emerging from the fibre is less than anticipated, the laser strikes should be stopped immediately and the cause investigated. A detailed description of this has been covered in earlier sections (Fig. 17).

10.6. Breakdown of equipment

Modern, well-maintained medical laser equipment is reliable and performs well. However, it is inevitable that, at some stage, the equipment will break down. Contingency plans are necessary to revert to more traditional ways of dealing with nasal pathology and to complete the procedure if feasible.

11. Benefits to the patient from laser technology

The use of laser technology in nasal surgery involves the conversion (absorption) of light energy into thermal energy. The effects of lasers on the nasal tissue are thus akin to thermal (hot or cold) effects from any other source, such as diathermy or cryosurgery. In diathermy, the amount of energy deposited in the inferior turbinate is imprecise. On the other hand, by controlling the various parameters, the laser energy deposited in the tissue can be controlled to a considerable extent, thereby limiting the unwanted effects on the tissue. As a result, the benefits to the patient are considerable, as described below.

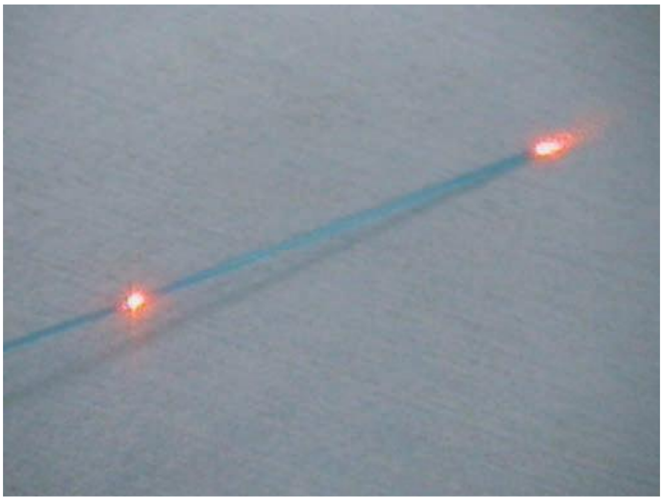


Fig. 17. A leaking fibre. If the energy emerging from the fibre is less than anticipated, the laser strikes should be stopped immediately and the cause investigated.

11.1. Minimally invasive surgery

Laser technology allows the targeted ablation of disease processes while retaining much anatomical, microscopic, and functional integrity, due to the tissue-sparing effect beyond the zone of thermal damage.

11.2. Minimal bleeding

Minimal intraoperative bleeding aids precision surgery and, in most cases, obviates the need for postoperative packing.

11.3. Minimal postoperative oedema and crusting

The lack of major operative trauma to the mucosa results in minimal oedema and crusting, thus adding to the comfort of the patient.

11.4. Revision surgery

Layer-by-layer removal of the tissue permits better orientation in revision cases, where anatomical landmarks are either lacking or distorted.

11.5. Ambulatory surgery

In most cases, it is possible to undertake surgery as a day care or an office procedure.

11.6. Cost benefit

Day-case surgery reduces the costs per procedure, and the patient can return to work within a short time after laser surgery. Although the cost per procedure is less because they are carried out on a day-case basis, the capital outlay is high and, in some cases, the revenue costs for single-use fibres are also high. These costs must be taken into consideration, together with those for breakdowns, maintenance, and replacements.

12. Assessment of laser surgery outcome

When comparing the outcome following laser surgery, there is an unwitting tendency to compare the effects of instrumentation, rather than its use in a particular disease entity and the skill of the operator. Laser turbinate reduction in allergic rhinitis cannot be expected to cure the allergy, although some relief from symptoms of allergy can be expected. The short- and long-term effects will depend upon surgical expertise, and the natural course of the disease, etc., irrespective of the instruments used.

Lasers can provide a relatively bloodless field so that surgery can be more precise. They also allow controlled preservation of normal tissues by depositing the energy in a well-defined targeted area. How much all of this affects the outcome for the patient is a debatable question on account of the multi-factorial aetiology of the nasal symptoms. One possible perceivable benefit for the patient is the lack of nasal packing following surgery. However, patients who have never undergone conventional nasal surgery before, cannot be expected to perceive even this benefit!

13. Laser safety

If the general safety regulations are observed correctly, the endonasal application of lasers does not create any additional specific hazards.

14. Laser terminology

Laser is not a replacement for conventional surgical methods; for example, surgery on the MMC must be carried out using both conventional and laser instrumentation. The term 'laser-assisted middle meatoplasty' seems more appropriate than 'laser middle meatoplasty' for such surgery. When laser is used for FESS, the procedure is known by the acronym FEELS (Functional Endoscopic Endonasal Laser Surgery).

15. Clinical laser applications in the nose

Almost any lesion in the nasal cavity can be tackled with the laser. However, the operator must have adequate experience in conventional endonasal surgery before embarking upon the use of a laser. It is necessary to have the correct instrumentation and monitoring equipment so that the team can watch the progress and anticipate each step of the procedure.

Laser surgery differs from conventional surgery in one important aspect: laser energy has a damaging effect on tissues beyond the laser strikes. The risk of complications can be avoided by following considerations:

- The beginner should practice the use of laser energy on animal tissue, which is easily available from any butcher's shop. A sheep's head is an excellent animal model for hands on training of FEELS (Hopf). The laser is used with various parameters and its effect is assessed by cutting the tissue through the area of strikes. A note is made of the useful parameters for soft tissue and bone ablation.
- It is advisable to avoid using the laser in the MMC until the operator has gained sufficient expertise from using it in safer places within the nose, has followed the postoperative course, and assessed the surgical outcome. The inferior turbinate is ideal for this initial safer application, since there are no vital structures in close proximity. The septum should be protected from inadvertent laser strikes with a nasal splint. The operator then gradually progresses towards tackling other pathology within the nose.
- Lasers offer some advantages over conventional methods for certain conditions in the nose. However, the operator should only use the laser when there is a clear advantage, and the risks from its use have been assessed, minimised, and eliminated where possible. As an example, reduction of the turbinates using a laser is a bloodless procedure in most patients and therefore postoperative packing is not necessary. This is a clear advantage over conventional reduction with a pair of scissors. However, unlike turbinectomy with scissors, laser reduction in close proximity of a deflected septum may result in septal perforation if inappropriate wavelength and inappropriate parameters are used. Thus, there is a potential risk to the patient of an adverse surgical outcome. In such cases, the risk should be minimised by using the laser energy submucosally or undertaking coagulation of a caudal strip under direct vision. The risk is completely eliminated by using a nasal splint to cover the septum.
- It is also useful to recognise the limitations of the laser. Removal of a neoplastic growth with a laser is painfully slow, and the use of power instruments to remove the bulk is more appropriate. The residual tumour can then be vaporised with the laser, since its thin fibre can easily reach inaccessible places. It also controls any oozing and covers the bed with a coagulum, forming a barrier against infection. These various issues are dealt with in greater detail in the following chapters, which cover laser usage in some common nasal conditions.
- Finally, it is useful to appreciate that every wavelength has its own set of tissue effects, quite dissimilar to other wavelengths. It therefore follows that, every time a different wavelength is introduced into clinical practice, the operator should establish the safe therapeutic parameters for that particular wavelength before using it in a clinical situation. This is particularly true when a new or different wavelength is being 'assessed' for potential purchase by the operator.
- An accredited laser course or peer supervision is always useful for the training of beginners.

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MCQ – 20. Endonasal laser applications

1. The most suitable laser for nasal surgery should
    a. Be fibre-transmissible
    b. Deliver high power
    c. Should have small spot size
    d. Should be haemostatic
    e. Should be a contact laser

2. CO_2 laser should be used for endonasal work because
    a. It is delivered as free beam
    b. Haemostasis for vascular nasal mucosa is adequate
    c. It is readily available in most ENT department
    d. It vaporises and coagulates tissue effectively
    e. None of the above

3. Pre-carbonisation of the fibre tip
    a. Increases the temperature at the tip of the fibre
    b. Reduces the temperature at the tip of the fibre
    c. Increases tissue ablation
    d. Increases coagulation effect
    e. None of the above

4. Laser beam exiting from the tip of the fibre
    a. Is collimated
    b. Is divergent
    c. Is distorted
    d. Can only be delivered when in contact with the tissue
    e. Delivers uniform energy irrespective of its application in contact or near contact mode

5. Ablation of the bony structures of the nose requires high power laser
    a. Because it is time consuming
    b. To avoid charring
    c. To avoid excessive collateral heat transmission
    d. All of the above

6. Multi-channel applicator systems are useful because
    a. They can be easily manoeuvred within the nasal cavity
    b. Smoke can be continuously removed to obtain adequate view of the target
    c. Fibre can be delivered in the close proximity of the target tissue
    d. Endoscope lens can be continuously irrigated and kept clean
    e. All of the above

7. Use of microscope for endonasal laser surgery
    a. Is cumbersome
    b. Overcomes the problem of soiling of the endoscope lens
    c. Provides magnified view of the target
    d. Does not provide adequate access to the posterior nasal structures
    e. All of the above

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8. Endonasal laser surgery
   a. Can be performed as an ambulatory procedure
   b. Is associated with significant postoperative bleeding and needs packing
   c. Is most suitable for revision cases since tissues can be removed layer by layer
   d. Posterior nasal surgery is possible without surgical removal of the obstruction in the anterior nose such as deviated nasal septum
   e. Is associated with significant postoperative oedema

Chapter 21

Laser-assisted dacryocystorhinostomy

V. Oswal,* P. Eloy,* A. Poirrier,* N. Jones and T. Dowd

Editors' note: In contrast to the classical external approach dacryocystorhinostomy (DCR) in the management of watering of the eyes, endonasal cold-instrument or laser DCR has gathered momentum in recent years, as shown by numerous publications. The authors of this chapter have updated the text from the first edition to cover continuing development in light of the experience gathered since the first edition was published in 2002. In a multi-authorship of any work, there are bound to be individual opinions and experiences which need to be honoured. Where a particular author has his own experience to relate, or where an opinion has been aired on a published work, the initials of the author appear in italics between brackets.

1. Introduction

In ophthalmology, watering of the eye (epiphora) is a common complaint. In some patients, epiphora causes a feeling of constant wetness in the eye while in others there is frank tearing. Wetness results in blurring of vision and loss of clarity. Tearing is a nuisance in social and work activities. It may be the cause of embarrassment, and tears may be perceived by others to be an emotional response.

The effects of epiphora are variable. Constant dabbing at and wiping of the eyes may represent purely an inconvenience or they may result in skin irritation, soreness and recurrent conjunctivitis. A blocked drainage system may act as a reservoir for bacterial infection, with episodes of acute dacryocystitis. Treatment with antibiotics for recurrent dacryocystitis offers only short-term remission, and restoration of drainage is often necessary to affect a cure.

In a small group of patients, epiphora needs to be corrected as a preliminary procedure to surgery for cataract, etc.

Not all patients suffering from epiphora seek advice (TD). For some, it is an inevitable consequence of 'growing old'. However, others do seek advice, which is appropriate since, in a significant number of patients, diagnostic syringing unblocks the system and cures the epiphora. If the blockage persists, the discussion of surgical management results in a number of patients opting for surgery.

Epiphora may result from excessive production of secretions by the lacrimal glands. Allergy, infection, chronic inflammation, or a foreign body may be responsible. However, in the vast majority of cases, epiphora is due to an obstruction in the drainage system (Jones, 1961). This obstruction may be present anywhere between the puncti in the medial canthus and the opening of the nasolacrimal duct in the inferior meatus. Tables 1 and 2 summarise the main causes of epiphora in general. In most cases, the aetiology of nasolacrimal duct obstruction is not obvious. Chronic dacryocystitis is believed to be the main culprit, but there is no plausible evidence. The diagnosis of 'epiphora of

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*Authors for the second-edition update.

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unknown aetiology' seems to be appropriate in most cases!

Table 1. Non-obstructive causes of epiphora.

1. Excessive tear production
2. Conjunctival chalices or folds, lid contour deformity
3. Deficiency in the lacrimal pump (VIIth nerve palsy, atonic eyelid, 'stiff eyelid' from burns, scar tissue, scleroderma, or slits in the openings of the canaliculus or ampulla)
4. Malposition of the punctum (ectropion, congenital displacement of the punctum)

Table 2. Obstructive causes of epiphora.

1. Stenosis or occlusion of the punctum (congenital, post-irradiation, chemical or thermal burns, post-injury, neoplasm, cicatrising infections, iatrogenic trauma due to repeated probing)
2. Obstruction of the lacrimal sac and lacrimal duct (idiopathic, nasal and mid-facial fracture, sinus surgery, orbital decompression, congenital, lacrimal sac or maxillary tumour, secondary to ethmoiditis, lacrimal casts)

Dacryocystorhinostomy (DCR) basically involves the creation of a surgical opening between the lacrimal sac and nasal fossa, at the nasolacrimal ridge, which lies just anterior to the bony attachment of the anterior end of the middle turbinate. This new opening is proximal to the site of obstruction, and re-establishes the flow of lacrimal fluid into the nasal fossa, thereby by-passing the obstruction in the nasolacrimal duct. There are two approaches: external and endonasal. The endonasal procedure can be undertaken with cold instrumentation (chisel, drill, and power drill) or, more recently, with the laser.

2. Literature review

Numerous articles have appeared in the literature on the topic of management of epiphora since the endonasal approach was introduced. Introduction of various lasers in clinical practice only served to increase the number of articles that have been published in the past decade. In this section we highlight some of the salient features which provide an overview on the subject of DCR and its management.

2.1. Terminology

Literature reviews shows an array of terminology used to describe the various approaches and the instrumentation used. Here we have listed the terminology used in this chapter and the corresponding abbreviations:

Dacryocystorhinostomy	DCR
External DCR	EX-DCR
Endonasal DCR	EN-DCR
Endonasal Laser DCR	ENL-DCR
Endonasal cold instrument DCR	ENCI-DCR
Endonasal radio frequency DCR	ENRF-DCR
Transcanalicular DCR	TC-DCR
Transcanalicular and Endonasal DCR	TCEN-DCR

2.2. Surgical approaches

There is no standardisation in the successful outcome criteria for various surgical approaches. A number of articles delve upon 95% success in obtaining resolution of epiphora by external approach as gold standard against which the success rate of all other methods is compared. The basis of this comparison ignores some important issues, such as post-operative bruising of the corresponding eye, morbidity, presence of facial scar, operative time and costs. In addition, there is one further important distinction between the external and endonasal approach: EN-DCR may give between 60 and 80% success rate as compared to 95% results of EX-DCR. By not using this approach, based purely on the higher success rate of EX-DCR, six to eight of every ten patients will end up having facial scar which could have been avoided if EN-DCR was used as the initial method of choice. Should first attempt of EN-DCR fail to produce resolution of epiphora, then, a revision procedure can easily be advised. A number of papers show an improvement in the rate of resolution following second revision surgery. Should these measures fail to resolve epiphora, then the EX-DCR can always be advised since previous failed EN-DCR does not preclude EX-DCR.

2.3. Use of stent

The role of the stent in ensuring that the rhinostoma heals without complete occlusion is not clear. The time span during which the stent should remain *in situ* varies considerably and again, there is no clear cut evidence for optimisation of duration.

2.4. *Mitomycin-C*

This anti-fibrosis preparation has been used as topical application at the site of operation to discourage fibroblastic activity. Again, there is no scientifically controlled study to show its effectiveness, and its use seems more empirical than tangible. This topic is covered in detail later in the chapter.

3. Summary of literature review

The following text has been provided for a busy practitioner to acquaint himself/herself with the current global thinking and pros and cons of the various management strategies for epiphora. The list is comprehensive, but not exhaustive.

i. Epiphora is not a serious condition; nevertheless, it has a considerable effect on the quality of life of patients who suffer from it.
ii. EX-DCR approach produces an equitable result of resolution of the symptom of epiphora in 95% of patients – a very acceptable outcome by any standard, both for the patient and the surgeon alike.
iii. However, EX-DCFR approach has downside when compared with the EN-DCR. The surgery is associated with a degree of postoperative morbidity, black eye and a permanent facial scar. It invariably requires general anaesthesia.
iv. Success rate following EN-DCR is dependent upon learning curve, and the instruments used. Initial low success rate does improve as one gathers experience through the passage of time and number of cases. Laser ablation of bony thickness of frontal process of maxilla requires high power with subsequent greater carbonisation, crusting, granulation and eventual restenosis in a number of cases. No particular laser is more advantageous in this respect. A number of authors use laser only for soft tissues and microdrill for removal of bone to create bony rhinostoma.
v. Transcanalicular use of optical laser fibre, without simultaneous monitoring of endonasal structures is not advisable. The fibre has a tendency to pass more in posterior direction due to anatomical factors and the stoma created via this route alone is placed more posteriorly. The stoma should be enlarged endonasally either with the laser or, preferably with the drill, in the anterior direction by removing part of the frontal process of maxilla.
vi. The use of a stent is common, although there are no controlled trials to establish its absolute role in lowering the rate of restenosis. The duration that the stent should remain *in situ* is also arbitrary.
vii. Surgical outcome is measured in terms of resolution of symptom of epiphora. Subjective method involves patient satisfaction score and visual inspection of the site of rhinostome. However, there is no direct relationship between the presence or absence of rhinostome, its ultimate size, its location and the resolution of epiphora. Objective method involves flushing the lachrymal system with fluorescence and checking its appearance at the site of rhinostoma, or / and at the natural opening of the lachrymal duct in the inferior meatus.
viii. A successful *anatomical* outcome confirmed by a presence of rhinostoma may not assure a successful *functional* outcome with complete resolution of symptom of epiphora.
ix. Complication rate for EN-DCR is significantly lower as compared to that of EX-DCR.
x. The choice method to obtain comparable published results is the one which works best for a particular surgeon!

4. Lacrimal apparatus

The lacrimal apparatus consists of the secreting lacrimal gland and the drainage system (Fig. 1).

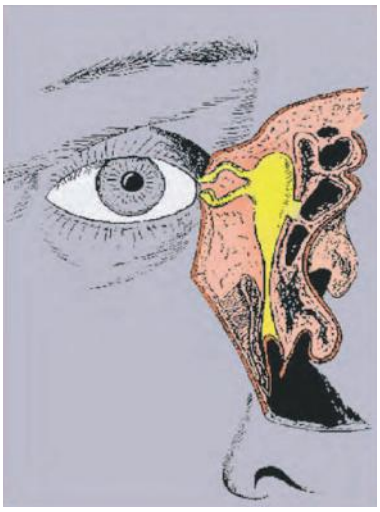


Fig. 1. The lacrimal apparatus.

The latter comprises the punctum in the medial canthus of each eyelid, leading to the ducts known as the upper and lower canaliculus. These two canaliculi join to form a short common canaliculus, which drains into the lacrimal sac. Here, the anatomy can be variable, and the upper and lower canaliculus may open separately into the sac. The lower opening of the sac is contiguous with the nasolacrimal duct, which ends in an opening in the inferior meatus (Fig. 2).

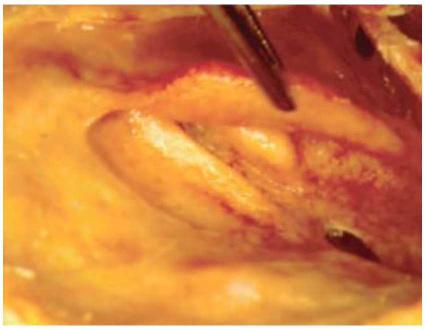


Fig. 2. The natural nasal opening of the lacrimal duct in the inferior meatus.

5. Anatomy of the lacrimal drainage system

The lacrimal drainage system is in the close vicinity of the orbit, its contents, the medial canthus ligament and ethmoid cells. It is necessary to appreciate the gross anatomy, surgical anatomy, as well as the endoscopic anatomy, since the endonasal approach has a definitive learning curve.

Furthermore, it is important to be aware of these anatomical landmarks while performing surgery of the osteomeatal complex. The duct may be injured during uncinectomy or by excessive resection of the anterior margin of the natural ostium of the maxillary sinus.

5.1. The canaliculi

An epithelial-lined system of ducts and the sac starts at the upper and lower lacrimal puncta located six mm laterally from the inner canthus. A canaliculus, just one mm in diameter, runs medially from each punctum to about eight mm. It has an initial vertical course of about two mm, at a right angle to the lid margin, followed by a horizontal excursion of about six to eight mm. In 90% of the population, the two canaliculi join to form the common canaliculus, two mm long, which opens into the lacrimal sac (Jones, 1961; Mondain *et al.*, 1992).

5.2. The bony lacrimal fossa

The lacrimal fossa, which accommodates the lacrimal sac, is found at the medial aspect of the orbital floor. It is delineated anteriorly by the anterior lacrimal crest, which is the superior-medial extension of the inferior orbital rim formed by the frontal process of the maxillary bone, and posteriorly by the posterior lacrimal crest, which is part of lacrimal bone. The anterior lacrimal crest is made of very dense bone and may overhang the lacrimal fossa considerably (Fig. 9a). The lacrimal fossa itself is paper-thin.

5.3. The lacrimal sac

The lacrimal sac extends inferiorly almost vertically for about 12-15 mm. About three mm of the sac lies above the opening of the canaliculus, and is known as the fundus. The lacrimal sac is in close contact with the medial canthal tendon, orbicularis muscle, and orbital septum. Intranasally, the lacrimal sac is found within bone located just anterior to the anterior attachment of the bony middle turbinate. The soft tissue covering the anterior end of the middle turbinate may be enlarged, and obstruct the operation site (Fig. 3).

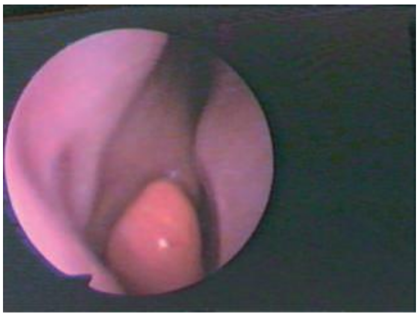


Fig. 3. Enlarged anterior end of middle turbinate may obstruct the operation site.

The relationship of the lacrimal sac to the ethmoid air cells is variable. In 15-20% of patients, the anterior ethmoidal cells may encroach upon the bony fossa along the posterior lacrimal crest, to a varying degree (Fig. 4a). In some cases, they may actually extend as far as the anterior lacrimal crest, lying between the lacrimal sac laterally, and the nasal cavity medially (Fig. 4c). However, in the majority of cases, ethmoid cells are found posterior to the lacrimal fossa (Fig. 4b).

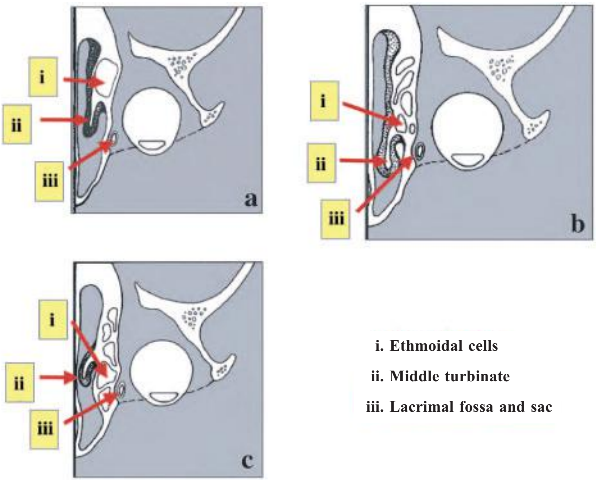


Fig. 4. a. The anterior ethmoidal cells encroach the bony fossa along the posterior lacrimal crest; b. In the majority of cases, ethmoid cells are posterior to the lacrimal fossa; c. In some cases, however, ethmoidal cells extend as far as the anterior lacrimal crest, lying between the lacrimal sac laterally, and the nasal cavity medially.

5.4. The bony nasolacrimal canal

The bony nasolacrimal canal is about 12 mm long and extends downward along the lateral nasal wall. It is made of maxillary bone anteriorly and lacrimal bone posteriorly. It ends into the superior wall of the inferior meatus, underneath the inferior turbinate. The nasolacrimal ostium may have a fold of mucosa referred to as the plica lacrimalis, the valve of Hasner, or the valve of Cruveilhier.

5.5. The membranous lacrimal duct

The membranous lacrimal duct lies within the bony canal and extends from the inferior portion of the sac into the inferior meatus. The duct has intraosseous and membranous parts. It is narrowest in the middle. It does not run directly inferiorly. It is angulated either inferio-medially or inferio-laterally by 5-16.5°. Onodi (1913) describes its surface marking with a line starting from the medial canthus to a point between the second bicuspid and the first molar. However, this point may be shifted posteriorly as far as the second or even third molar. The duct lies in close proximity to the maxillary sinus and anterior ethmoidal cells.

The prominence of the duct can be seen within the maxillary sinus. Its nasal opening is situated about one cm posterior to the anterior end of the inferior turbinate and 16 mm superior to the floor of the nasal fossa (Fig. 2).

It is clear that, in a neoplastic process of the maxillary sinus, it is invasion of the nasolacrimal duct and sac that results in epiphora as one of the main symptoms.

6. Surgical anatomy of the lacrimal apparatus

Raut *et al.* (2000) studied the lacrimal apparatus in the nose of ten cadaveric half-heads (five males and females) in order to establish the anatomical landmarks and most accessible part of the lacrimal duct from within the nose. Although there was solid bone covering the whole length of the sac and the duct, the posteromedial aspect of the lower sac and upper duct was covered by the ultra-thin lacrimal bone (average thickness 0.057 mm). The ultra-thin bone was consistently found to be lying immediately anterior to the uncinate process in the middle meatus, thus constituting a 'surgical window' (average size 2.5 x 7.2 mm) whereby surgical entry into the lacrimal duct becomes relatively easy. Therefore, the lower part of the lacrimal sac and the upper part of the lacrimal duct can easily be accessed from within the nose by following this anatomical approach, thus avoiding the need to drill or chisel the dense frontal process of the maxilla.

In the view of one of us (VO), this finding is of little consequence since the posteromedial surface of the lacrimal fossa is quite inaccessible as a starting point for the removal of bone. Several 'normal' anatomical variations in the structures in the vicinity of the fossa obscure it in a significant number of cases. These variations include the size and position of the middle turbinate, an overhanging anterior lacrimal crest, an enlarged concha bullosa, etc. Nevertheless, if the access is unimpeded, then removal of bone posterior to the transillluminated site is probably easier, bearing in mind that the 'window of Raut' is only 2.5 x 7.2 mm and, therefore, a narrow elongated strip of bone should be removed with great precision. In order to reconfirm the classical teaching in the current literature that the lacrimal sac is situated anterior to the anterior end of the middle turbinate, with between 0% and 20% of the sac above the insertion of the middle turbinate on the lateral nasal wall, Wormald *et al.* (2000) set out to study the relationship between the lacrimal sac and the lateral nasal wall. With the help of CT dacryocystograms (DCGs) and

CT scans in 47 individual lacrimal sacs, they found that the mean height of the sac above the middle turbinate insertion was 8.8 mm (SD = 0.2, 95% CI = 1.3), and below this was 4.1 mm (SD = 2.3, 95% CI = 1.1). The average measurement of the sac above the common canaliculus on CT DCGs was 5.3 mm (SD = 1.7, 95% CI = 0.56), whereas the average measurement below the common canaliculus was 7.7 mm (SD = 2, 95% CI = 1.3) (*n* = 47 CT DCGs). The findings in this study show that a major portion of the sac is located above the insertion of the anterior end of the middle turbinate.

This finding has important bearing on the site as well as on the size of the opening (VO). Failed DCR caused by the presence of a residual lacrimal sac has been termed the 'lacrimal sump syndrome' (Migliori, 1997). Irrigation of the system may show a patent sac, but epiphora continues when tears, or more importantly mucus, collect in this residual pouch and lacrimal drainage is impaired. This condition can easily be diagnosed with nasal endoscopy and has a characteristic radiological appearance. It is therefore important that the opening in the sac extends adequately in an inferior direction. Furthermore, to make a decent-sized opening (~ 5 mm), it is necessary to enlarge it in an upward direction, where the bone gets even thicker!

7. Clinical evaluation

Patients suffering from epiphora are referred in the first instance to the ophthalmic department. A thorough ophthalmic and nasal examination usually fails to show any obvious aetiological factors in the majority of cases. The patency of the system is tested by flushing it with saline solution introduced into the lower canaliculus, with one of the following results:

- *No obstruction:* in the absence of obstruction, the saline passes down the system into the nose and the oropharynx where it evokes a sensation of salty taste. The cause of epiphora may then lie in the inadequacy of the lacrimal pump. In some cases, the punctum may not be in contact with the conjunctiva of the eyelid because of malposition.
- *Inability to flush:* failure to flush indicates a stenosed punctum, canaliculus, or both. Examination of the punctum may show it to be extremely small. Probing the lacrimal pathway with a smooth double-ended Bowman's probe may end in a 'soft stop' confirming a canalicular pathology. In some cases, probing and dilatation may be successful in re-establishing the patency of the system. In resistant cases, the management of epiphora due to a stenosed punctum or canaliculus is undertaken by the ophthalmologist with a 'three-snip procedure', which enlarges the opening.
- *Regurgitation through the upper punctum:* if saline regurgitates through the upper punctum, then it may have entered the sac and regurgitated through the common canaliculus into the upper canaliculus or alternatively met an obstruction at the common canaliculus and regurgitated through the upper canaliculus. A common canalicular obstruction typically results in a 'soft stop' on probing, whereas a sac or distal obstruction usually results in a 'hard stop'. It is important to differentiate common canalicular obstruction from sac or distal obstruction as the treatment will be different.

Flushing should be undertaken gently since it can cause damage to the delicate canaliculi and produce a false passage.

Some cases present with both proximal and distal obstruction. Endonasal DCR alone is inadvisable in all but minor cases of proximal obstruction since the results are invariably disappointing. When the obstruction is solely due to a stenosed punctum, a simultaneous three-snip procedure forms an integral part of the endonasal DCR surgery.

Simple massaging of the sac may produce pus or discharge from the puncti, indicating a diagnosis of chronic mucoid or purulent dacryocystitis. Lacrimal mucocoele or pyocoele present as a visible and palpable swelling, infero-lateral to the medial canthus (Fig. 5a,b).

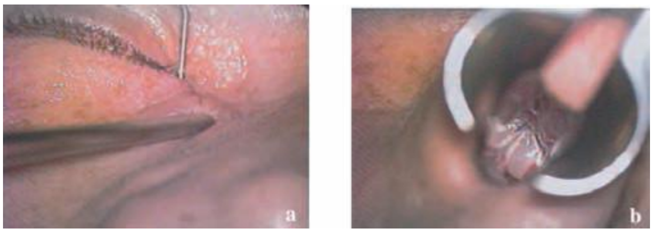


Fig. 5. Lacrimal mucocoele. a. Preoperative; b. Intraoperative.

8. Dacryoendoscopy

In some centres, ophthalmologists use a dacryoendoscope to evaluate the mucosa and the contents of the lacrimal system. This technique is not really new as the first trials were made more than ten years ago in France, Austria or in Germany (Emmerich, 1997; Müllner *et al.*, 1999; Ebran *et al.*, 1989; Brémond-Gignac *et al.*, 1999; Baggio *et al.*, 2005; Fein *et al.*, 1992; Singh *et al.*, 1992; Kuchar *et al.*, 1997).

While at the outset dacryoendoscopy seems an ideal way to inspect the luminal mucosa of the lacrimal pathway directly, there are a number of technical and logistic difficulties associated with this useful investigation.

The size of the mini-endoscope is quite small. There are two different systems: one for the diagnosis and another for the therapy. The diagnostic system has an outer diameter of 0.9 mm. The system for therapy has a working channel and the outer diameter is a little bit bigger: 1.1 mm.

The mini-endoscope is linked to a video camera and a light source but because of the diameter of the endoscope, the resolution of the image is not very high.

Dacryoendoscopy is not widely used since the equipment is not marketed widely. The method of sterilisation is also controversial. Also, it has a steep learning curve.

Nevertheless, the dacryoendoscopy is an excellent method to investigate the lacrimal system since it is the only investigation which provides direct visual information about the state of the mucosa and the nature of the contents of the lacrimal system.

In some German centres, this method of diagnosis is used as the sole investigation to diagnose lacrimal path way obstruction. A patient with a lacrimal system disorder is taken to the operating facility. A preliminary dacryoendoscopy is carried out and the treatment is tailored to the findings: either a dacryocystorhinostomy is carried out for obstruction, or, dacryoplasty (endolumination rechannelisation procedure) for fibrosis, thickening of the mucosa, etc. Its clinical use is described later.

In the vast majority of patients, obstruction of the lacrimal duct is the sole cause of watering, and the most common aetiology is idiopathic. In the context of the DCR operation, a diagnosis of obstruction of the lacrimal duct is by exclusion of obstruction at other sites. It is often seen in elderly women, in whom it is five times more common. It is postulated that a combination of anatomical factors, endocrine changes, and chronic sinus infection is possibly implicated. The duct lining becomes oedematous, and stenosis and cicatrisation take place within the vascular plexus surrounding the membranous nasolacrimal duct.

An endoscopic examination of the nasal passage is mainly directed at ensuring adequate access to the operation site by excluding such causes as marked deviated nasal septum, gross polyposis, chronic sinus or nasal infection and neoplastic lesions. If any nasal conditions are found, then preliminary or concurrent management is planned as appropriate, with the proposed DCR. However, surgery is contra-indicated in cases of active Wegener's granulomatosis.

The finding of chronic past or current pathology of the nose, or any history of previous nasal surgery, would have an unfavourable outcome on the surgical outcome of EN-DCR because thickened or scarred mucosa predisposes to further scarring. It may be that such patients are advised to have primary external surgery, in which wide excision of the mucosa can be undertaken under direct vision, and a much larger opening is made.

9. Investigations

CT scanning is not usually advised, unless there is suspicion of a neoplasm. Neither is a DCG performed routinely, since there is an associated risk of trauma, it requires an experienced radiologist, and yields very little additional information to influence management with DCR. A radioscintillogram, which consists of instilling radio-opaque dye into the conjunctival sac and its detection in the nasal passage, also yields little additional information, unless functional outflow obstruction is suspected and needs to be confirmed (Amonat *et al.*, 1979; Eloy *et al.*, 1995; Jenny *et al.*, 1984; Mannor and Millman, 1992; Montecalvo *et al.*, 1990).

Francis *et al.* (1999) evaluated the role of CT in 107 cases of dacryostenosis (94 patients). Examination of the lacrimal drainage system included state and position of the puncta, Jones' testing, lacrimal syringing, and, in the latter half of the study, telescopic nasal endoscopy. In 14 of the 107 cases (12 patients), preoperative CT led to an alteration in patient management, usually referral to an otolaryngologist for further evaluation or treatment. In addition to the detection of two tumours extrinsic to the sac, conditions such as ethmoiditis, lacrimal sac mucocoeles, soft tissue opacity in the nasolacrimal duct, gross nasal polyposis, fungal sinusitis, and a dacryolith, were diagnosed by CT.

CT scanning is indicated if there is a history of a facial fracture or suggestion of intranasal pathology. The diagnosis of lacrimal obstruction is made by the ophthalmic surgeon in the first place, but a full assessment by an otolaryngologist helps as it is adequate to exclude significant intranasal pathology. CT scanning is rarely necessary.

10. Indications for dacryocystorhinostomy

DCR is only indicated in cases that have an obstruction in the nasolacrimal duct. It is not indicated for obstruction in the puncti, canaliculi, common duct, or lacrimal sac. However, O'Donnell and Shah (2001) suggest that patients with patent drainage systems also benefit from DCR. They base their finding on the fluorescein dye disappearance test and Jones' tests 1 and 2, with dacryocystography in borderline cases.

11. Contra-indications for an endonasal approach

An endonasal approach is inappropriate in the presence of benign or malignant lesions of the lacrimal system or the surrounding tissues, as well as in Wegener's granulomatosis.

12. Surgical approaches to DCR

The management of an obstructed lachrymal system can be undertaken in various ways:

- The external approach;
- The endonasal approach: this may be with cold instruments alone, or with laser, or a combination thereof;
- The transcanalicular approach;
- The combined transcanalicular and endonasal approach: This is a laser-assisted procedure, with some steps undertaken with cold instrumentation;
- The dacryoplasty, a laser-assisted procedure.

Each approach has its pros and cons and also, each approach has a bearing on the short, medium and long term surgical outcome. Furthermore, patient morbidity, in-patient 'down' time, complication rate, cost economics, frequency of revision procedure, hi-tech equipment and skill demands are also significantly different. It is therefore appropriate that a fuller discussion takes place between the surgeon and the patient and the most suitable option chosen (PE*, AP*).

12.1. External approach: EX-DCR

The external approach was first described by Toti, an Italian rhinologist, in 1904 (Toti, 1904), and subsequently modified by other authors (Mosher, 1921; Pico, 1971). The external approach remains a gold standard against which the endonasal or transcanalicular approach attracts comparison. It provides wide exposure of the lacrimal system and allows management of a number of conditions causing epiphora. The operation is usually undertaken by an ophthalmologist specialising in this type of surgery. A detailed description of this approach is outside the scope of this book. In experienced hands, a success rate of 95% has been reported (Tarbet and Custer, 1995; Dior WX, Lee *et al.* 2010). Surgeons who carry out this procedure occasionally may have a lower success rate.

12.2. Endonasal approach: Literature review

The endonasal approach (Fig. 6) was first described by Caldwell in 1893, and, in 1914, West advocated it as the first-line treatment for lacrimal duct obstruction. However, it did not gain wide acceptance for a number a reasons. Primitive and unreliable illumination of the nasal cavity did not allow for a good view of the operation site. Intraoperative nasal bleeding obscured the view, generally contributing to poor results.

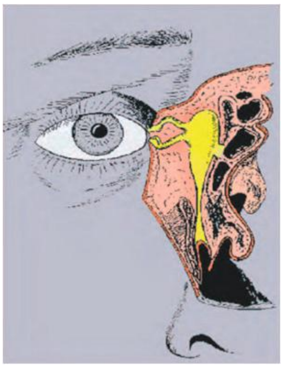


Fig. 6. The endonasal approach for EN-DCR.

In the 1980s, there was renewed interest in the endonasal approach, no doubt prompted by the general evolution of endonasal procedures such as functional endoscopic sinus surgery (FESS), and the introduction of vastly superior and reliable instrumentation (Rouvier *et al.*, 1981). In the current literature, there are reports of a success rate of 80-95% with this technique (El Khoury *et al.*, 1992; Eloy and Rouvier, 1995). Endonasal DCR is suitable for all cases of distal (low) idiopathic lacrimal pathway obstruction. It can also be used in cases of acute dacryocystitis refractory to medical treatment. Since the procedure is undertaken entirely through the nostril, there is no facial scar, or indeed disruption of the important medial canthal structures, thereby preserving the integrity of the lacrimal pump described by Jones (Becker, 1992).

The operation can be performed under either local or general anaesthesia as per patient and surgeon preferences. The site of the fistula is accessed by using an operating microscope with a self-retaining Killian's speculum, or rigid naso-endoscope (Rodlen's telescope). Any associated pathology such as a deviated nasal septum, nasal polyps, or a pneumatised middle turbinate (concha bullosa), may need initial management (Allen *et al.*, 1988; 1989; Welham and Henderson, 1973).

Endonasal DCR is mainly an ENT-oriented procedure since most of the surgery involves working in the nasal fossa. However, close cooperation with the ophthalmic department is essential in order to ensure correct diagnosis and referral of appropriate cases. The lacrimal system is composed of ducts and the sac lined by delicate mucosa. During the surgical intervention, assistance from the ophthalmologist in passing a vitreoretinal light pipe to transilluminate the site of the operation is useful (Von Buren *et al.*, 1994). The intervention is preferably undertaken by an experienced ophthalmologist rather than a make do assistant. Some patients may have additional pathology such as a stenosed punctum, which requires concurrent management by means of a three-snip procedure. Patients who fail to obtain benefit from endonasal DCR will require an external approach, which is usually carried out by the ophthalmologist. Therefore, it is advisable that an otolaryngologist-ophthalmologist team is formed to undertake endonasal DCR jointly.

The surgical procedure is carried out in four steps (Rouvier *et al.*, 1981; Rice, 1988; McDonogh and Meiring, 1989; Eloy *et al.*, 1991; Metson, 1995; Sprekelsen and Barberan, 1996), as follows:

- *Denudation of mucosa:* the first step consists of the removal of nasal mucosa covering the lacrimal fossa, which is located endonasally just anterior to the anterior attachment of the bony middle turbinate (Fig. 7a).
- *Removal of bone:* the second step is resection of the bone on the medial surface of the lacrimal groove. This can be performed with a Kerisson's forceps, a backbiting forceps, a drill, or a gauge (Fig. 7b). A diamond drill is needed to optimise wide exposure and removal of bone from the upper part of the anterior lacrimal crest. The difficulty of this step depends on the thickness of the bone formed by the naso-frontal process of the maxilla. Posteriorly, the resection of the paperthin lacrimal bone is easier and should complement removal of the frontal process of the maxilla.
- *Opening of the lacrimal sac:* the third step is the opening into the nasolacrimal sac (Fig. 7c). The site of the opening into the lacrimal sac can be monitored by transillumination provided by a light pipe passed gently through the inferior canaliculus into the sac. Alternatively, an assistant passes a probe into the sac and tents the mucosa medially, into the bony opening.
- *Insertion of a stent:* a bicanalicular nasal silicon stent (Fig. 7d), in the form of one-mm diameter solid tubing is used by some surgeons to maintain the patency of the opening (Adenis *et al.*, 1996; Allen, 1989; Fayet *et al.*, 1989; Hausler and Caversaccio, 1998; Older, 1982). One end of this tubing is inserted and fed through the upper, and the other through the lower, canaliculus so that the ends come out of the new opening into the nasal fossa. These are gently tightened so that only a small loop remains at the inner canthus. The ends are held *in situ* by a Watzke sleeve (Fig. 7e), and the excess tubing is cut short. The stent is left *in situ* for from six weeks to six months, depending upon individual practice. It is then removed by snipping the loop at the inner canthus and pulling the sleeve from the nostril. It is best to avoid excessive tightening of the loop as this causes 'cheese wiring' of the canaliculi (Fig. 7f).

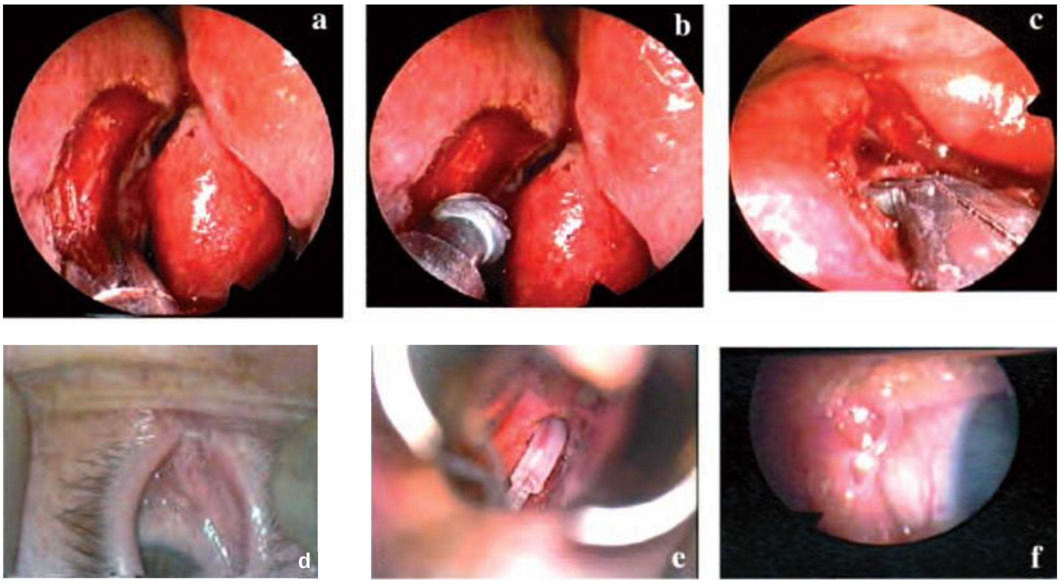


Fig. 7. DCR with cold instruments. a. Denudation of bone; b. Removal of bone with drill; c. Opening into the sac; d. Bicanalicular stent; e. The ends are held *in situ* by a Watzke sleeve; f. Excessive tightening of the loop causes 'cheese wiring' of the canaliculus.

13. Comparison of external versus endonasal dacryocystorhinostomy (EX-DCR versus EN-DCR)

Although external approach remains gold standard with a success rate approaching 95% for curing epiphora, there is a trade-off. Unlike the endonasal approach, which can be performed under general or local anaesthetic, the external approach requires general anaesthetic in most cases, and the patient has to be admitted as an inpatient. The approach requires a facial incision, which heals leaving a scar. In skilled hands, this scar tends to be small and neat and, with the passage of time, it is hardly noticeable. Nevertheless, patients do not take kindly to the prospect of having a scar on their face. A scar may also interfere with their ability to wear spectacles. Preliminary dissection of the tissues of the medial canthus is required for a wide exposure. This step has the potential to damage the medial canthal ligament and muscles, thus impeding the action of the lacrimal pump described by Jones. In some cases, there may be troublesome intraoperative bleeding, particularly from the nasal mucosa. The haemostasis requires nasal packing, which is rather uncomfortable, if not painful. For the first few days postoperatively, patients may have unsightly periorbital bruising. A certain degree of postoperative morbidity is thus unavoidable, but its severity varies from patient to patient.

A prospective randomised comparison between endonasal endoscopic dacryocystorhinostomy (EN-DCR) and external dacryocystorhinostomy (EX-DCR) was undertaken by Hartikainen *et al.* (1998) with regard to success rate, surgical duration, and postoperative symptoms. Sixty-four cases (60 patients) with primary acquired nasolacrimal sac or duct obstruction were divided into two subgroups by symptoms (simple epiphora/chronicdacryocystitis). The patients were randomised within both subgroups into two operation groups. In total, 32 EN-DCRs and 32 EX-DCRs were performed. The final follow-up visit was at one year. The patency of the lacrimal passage was investigated by irrigation, and patients were questioned about their symptoms.

The success rate at one year after primary surgery was 75% for EN-DCR and 91% for EX-DCR. This difference was not statistically significant ($p = 0.18$). The success rate after secondary surgery with a follow-up time of one year was 97% in both study groups. The average duration was 38 minutes for EN-DCR and 78 minutes for EX-DCR ($p < 0.001$). Hartikainen *et al.* concluded that, when compared with EN-DCR, EX-DCR appears to give a higher, although not statistically significant, primary success rate. However, the secondary success rates were equal, indicating that both these DCR techniques are acceptable alternatives.

This comparison is useful, but not altogether valid. If a higher success rate is the only criterion used when choosing the surgical method in all patients, then 75% of EX-DCR patients would undergo more extensive surgery with possibly a greater risk of complications. Tsirbas and McNab (2000) noted that secondary haemorrhage after DCR occurred in 3.8% of DCR cases. Risk factors included immunocompromised patients and those taking NSAID. The haemorrhages did not adversely affect the surgical outcome.

Ibrahim *et al.* (2001) classified surgical outcome into the following categories: complete anatomical and physiological success; anatomical success with partial relief of symptoms; anatomical success with no relief of symptoms; and anatomical failure. One hundred and ten EX-DCR and 53 endonasal-DCR (EN-DCR) procedures were evaluated. Free communication (anatomical success) was achieved in 82% of patients undergoing EX-DCR and in 58% undergoing EN-DCR. A significant number of patients continued to have symptoms in spite of a patent fistula (54% for EX-DCR and 39% for EN-DCR). The site of the opening of the internal ostium was significantly related to the persistence of symptoms, despite free communication ($p < 0.001$, χ test). Ibrahim *et al.* concluded that the standard EX-DCR technique had a higher anatomical success rate than endoscopic laser DCR, but not necessarily with an equivalent higher rate of relief of symptoms. An inferiorly placed ostium is more likely to result in the complete relief of symptoms.

14. Patient counselling

Patient counselling must cover not only the logistics of admission and consent for the operation, but also a full appraisal of the risks and benefit (VO). As will be seen below, although the steps of the operation are uniform in most cases, the surgical outcome is not consistent. There is also the question of variations in operator-opinion on the issues of the use of stents, mitomycin-C, etc. Revision surgery is not always an indication of inappropriate primary surgery, although, it must be admitted that there is a steep learning curve with DCR, and the initial results may be disappointing for both the patient and the surgeon alike.

Each patient's perception of the problem will be affected by his or her psychology, life style, employment circumstances, and willingness to undergo surgery (TD). The patient is informed of the procedure in detail, with the help of diagrams. The policy of one of the present authors (VO) is to advise the patient on the various options, mentioning a possible success rate of 70% with endonasal laser-DCR. If the first attempt at laser-DCR results in failure, then one further laser attempt could be advised. If the second attempt also results in failure, the patient is given the option of an external approach. If there is any associated pathology such as deviated nasal septum (DNS), minor proximal obstruction, previous history of nasal surgery, etc., then a lower success rate is quoted.

15. Endonasal *laser* dacryocystorhinostomy

Since its introduction into surgical practice, laser technology has improved the operative management of a number of procedures. In ENL-DCR, it can be used for the bloodless vaporisation of mucosa and for the ablation of bone (Bartley, 1994; Harris and Nerad, 1994). ENL-DCR operation is similar to the cold-instrument endonasal DCR described earlier, with the exception that the laser energy is used to vaporise the mucosa and ablate the bone in order to create a fistula. The major difference between the power/mechanical instrument and the laser energy is that the cold instruments do not heat up the surrounding tissues, whereas the laser energy does. The extent of the thermal damage and necrosis of the surrounding bony tissue is wavelength-dependent. Fxcessive thermal damage results in a gross inflammatory response with much fibrosis, leading to a high failure rate. In theory, therefore, the Ho:YAG and the Star pulse KTP/ 532 that ablate the bone efficiently seem to score points. In practice, however, there are many variables and reports in the literature suggest an overall success rate of about 70-80%, irrespective of the wavelength used (Fison and Fragoulis, 1989; Kong *et al.*, 1994; Massaro *et al.*, 1992; Metson *et al.*, 1994; Mickelson *et al.*, 1997; Reifler, 1993; Sadiq *et al.*, 1997; Seppa *et al.*, 1994; Woog *et al.*, 1993).

However, the success rate following endonasal DCR is somewhat higher (80-95%) than that achieved for ENL-DCR (70-80%) (Boush *et al.*, 1994). The better surgical outcome with conventional endonasal surgery is probably related to a wider bony opening.

The lacrimal prominence is formed by two bones, the *anterior* thick frontal process of maxilla and *posterior* thin lacrimal bone. The anterior thick bone requires much greater ablative laser energy. This leads to considerable carbonisation, greater thermal damage of the tissue, crust formation, granulation formation and therefore, a higher incidence of stenosis due to healing by fibrosis.

The shortcomings of the laser usage on the thick frontal process of the maxilla are overcome by drilling out the thick process, thereby reducing the fibroblastic reaction. Metson (1993) and Basmak (2010) proposed the use of a drill to widen the stoma endonasally. Basmak reported: 'Final anatomical success rates were 27/38 for group 1 (endocanalicular laser DCR) and 39/42 for group 2 (endocanalicular laser DCR + concomitant use of drill, $p = 0.02$). Final functional success rates were 25/38 patients in group 1 and 36/42 in group 2 ($p = 0.07$).'

Yung and Hardman-Lea (1998) reported the removal of only the inferior portion of the lacrimal sac and the adjacent duct with cold instruments. The sac is then marsupialised into the nose. The operation did not require sophisticated instruments and a high success rate of 90% was obtained in 81 consecutive endoscopic inferior DCRs.

15.1. Which laser?

Although the CO_2 laser is the most widely used laser in ENT departments, it is not suitable for DCR, which requires the creation of a bony fistula. The CO_2 laser energy is maximally absorbed by water. Since the water content of bone is very low, CO_2 energy is not well absorbed in bone. As a result, the bone undergoes charring rather than vaporisation. Continuing application of the energy to create an adequate fistula simply results in more char formation, increases tissue temperature, and causes extensive collateral thermal damage. Furthermore, the CO_2 laser cannot be transmitted via an optical fibre. Its delivery via waveguide results in much loss of energy, and leads to even more charring. The waveguide is substantially bulky compared to the small diameter fibre, which is easily manoeuverable.

Almost all other lasers, such as the KTP/532, diode, and Ho:YAG, are suitable since their energy can be delivered to the operation site via the flexible optical fibre, in conjunction with an endoscope or microscope.

The Ho:YAG laser has a high pulse energy, which ablates bone to white ash. It is also an efficient haemostat. The fibres have multiple use specifications and the cost per procedure is significantly less. The major disadvantage is the splattering of tissue with soiling of the lens, requiring frequent cleaning. The use of the microscope avoids soiling, but adds to the operating time because of the cumbersome and bulky equipment.

The KTP/532 laser, in its new Star pulse version, is most suitable since it vaporises the bone effortlessly and without splattering. It is also a good haemostat.

Diode laser energy can be delivered transcanalicularly or endonasally. It has sufficient power to ablate bone. The major disadvantage of the KTP and diode lasers is that the optical fibre is only marketed for single use. The cost per procedure for both KTP and diode lasers is thus significantly high. However, future developments in fibre technology are bound to address this issue and make the application of these useful wavelengths a viable proposition.

Caversaccio *et al.* (2001) used an Er: YAG laser to perform surgery on 12 patients. Eight cases had presaccal stenosis and four postsaccal stenosis. An erbium laser with a specially designed handpiece was used endonasally and transcanalicularly. Double bicanalicular nasal silicone tubes were placed in all cases. There were three failures: two with presaccal and one with postsaccal stenosis.

Irrespective of the type of laser used, standard safety precautions must be observed by the laser team, to protect the staff and the patient from inadvertent strikes and accidents. Chapter 3 covers laser safety in detail.

15.2. Access to the operation site

The endonasal operation site is accessed with either a microscope (Fig. 8) or an endoscope (Gonnering *et al.*, 1991; Metson *et al.*, 1994; Sadiq *et al.*, 1997; Seppa *et al.*, 1994; Weidenbecher *et al.*, 1994; Woog *et al.*, 1993).

When the operating microscope is used, the 300-mm objective is further away from the operation site and thus remains soil-free. It also provides useful magnification. Killian's speculum is placed in the nostril and the transilluminated site is located. However, the microscope is cumbersome and, in inexperienced hands, its use can add significantly to the operating time.

The endoscope is easier to manipulate, but the lens gets foggy due to smoke, blood, and debris,

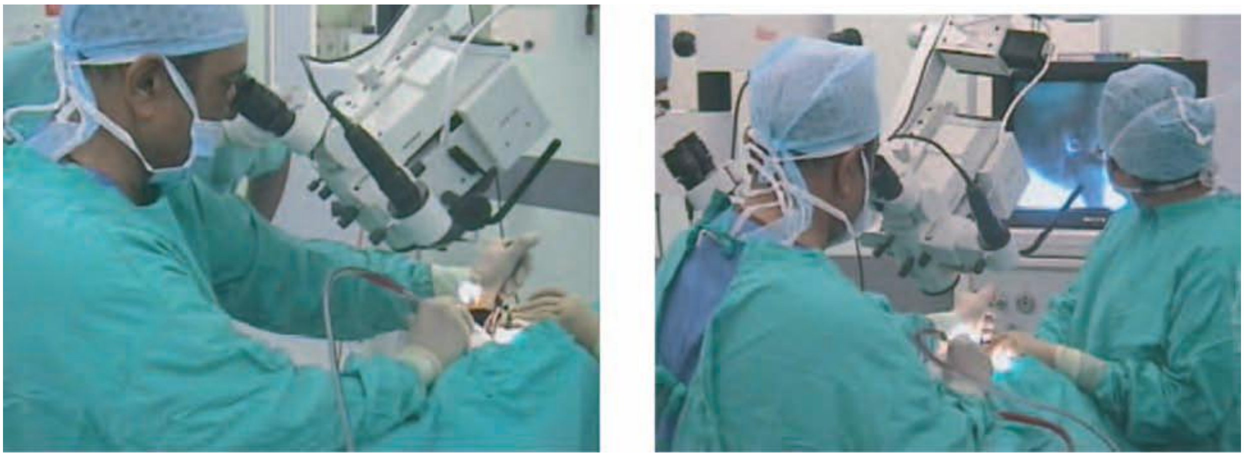


Fig. 8. Access to the operation site for DCR with microscope, which provides magnification. (Right) The ophthalmic surgeon manoeuvres the light pipe to provide sharp and bright transillumination.

and requires frequent cleaning, particularly when being used with the pulsed Ho:YAG laser. Thus, each method has its advantages and the choice depends on individual training, preferences, and the availability of the equipment and dedicated instruments.

15.3. The nasal fossa

The nasal fossa at the proposed operation site is decongested by inserting a half-inch ribbon gauze soaked in nasal decongestant.

15.4. Dilatation of the punctum

The lower punctum is dilated and a light pipe is inserted (Fig. 9a-d).

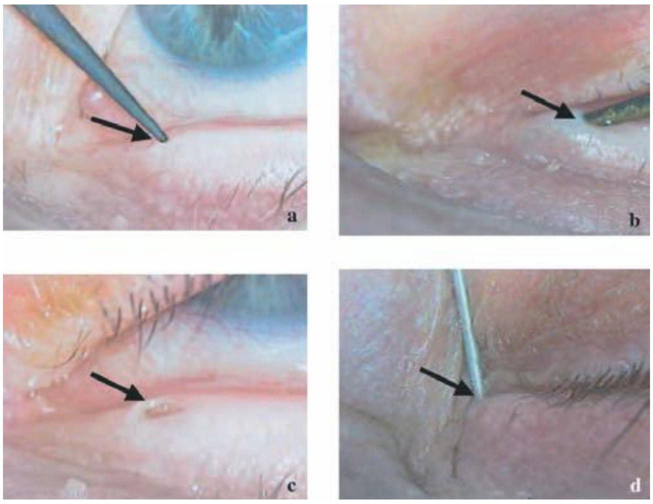


Fig. 9. The lower punctum is dilated and the light pipe is inserted.

The pipe is then advanced, initially in a vertical direction for one mm or so, and then horizontally towards the medial canthus until it butts against the bone (hard stop). If the resistance felt by the pipe at this point is soft (soft stop), it indicates a soft-tissue obstruction, either in the canaliculus or common duct. It is then necessary to revise the diagnosis since the DCR operation is not indicated in cases where the obstruction is proximal to the sac.

From the hard stop, the pipe is withdrawn slightly and advanced in an inferior-medial slanting direction so that it passes into the lacrimal sac. Some surgeons prefer to use the upper punctum for this stage of the procedure.

15.5. Localisation of the transillumated site

The ribbon-gauze is removed, the endonasal illumination is dimmed and the transilluminated site is located. If the light pipe is accurately positioned, it is usually seen as a bright and sharp illumination underneath the tissues, just anterior to the attachment of the bony middle turbinate (Von Buren *et al.*, 1994).

However, the light beam is not always easy to locate. This can be aided by further manipulation of the light pipe. Even if the light is located, it may be diffuse rather than bright and sharply demarcated, due to a number of factors:

- *Hypertrophied anterior end of the middle turbinate:* enlargement of the soft tissue covering the anterior end of the middle turbinate may obscure part of the beam and may need reduction with the laser (Fig. 3).

- *Bulky middle turbinate:* the space between the lateral surface of the middle turbinate and the lateral wall may just be a slit, needing infracturing of the turbinate.
- *Thick mucosa or bone:* the mucosa covering the anterior lacrimal crest may be thick and require vaporisation so that the transilluminated light becomes brighter. Likewise, the bone covering the sac is sometimes very thick, preventing bright transillumination (Fig. 10a-d).

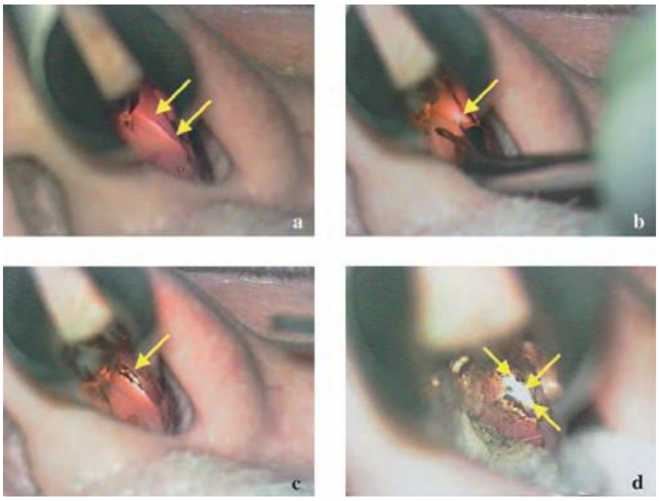


Fig. 10. a. Diffuse transillumination due to overhanging prominent anterior lacrimal crest; b. Oswal suction-fibre cannula; c. Crest removed with Ho:YAG laser; d. Transillumination becomes sharp and bright.

- *Agger nasi or anterior ethmoid cells:* in 8% of cases, the illumination is rather diffuse on account of interposition of the agger nasi or an anterior ethmoid cell between the sac and the nasal fossa. In such cases, uncapping the cell with the laser results in increased brightness of the illumination. Further vaporisation can then be carried out safely in the direction of the light (Fig. 10c).
- *Lacrimal mucocoele or pyocoele:* the beam may also be very diffuse instead of sharply delineated, due to the presence of mucocoele or pyocoele of the sac.

When the beam is not bright and sharp, due to the presence of any of the above factors, one should proceed with caution and undertake a saucer-shaped vaporisation over the most brightly illuminated area. The light should get brighter as successive layers of mucosa and bone are vaporised. If there is any doubt as to the accuracy of localisation, the procedure should be abandoned.

15.6. Laser delivery to the operation site

The optical fibre is taken to the operation site through a two-channel handpiece, the second channel is used to evacuate any smoke and debris generated at the operation site. The distal end is bent by about 25° so that the beam is directed laterally. Oswal designed a three-channel handpiece in order to address the considerable splattering caused by the Ho:YAG laser. The additional third suction channel extends right up to the operation site and removes tissue debris instantly (Fig. 10b-d).

15.7. Vaporisation of mucosa and bone

When a sharp and bright spot is located, an area of the mucosa covering the medial surface of the lacrimal bone in the lateral nasal wall is vaporised. The laser energy is then applied to the bone and vaporisation is carried out (Fig. 11). The transilluminated beam is followed to make a shallow pit about 4-5 mm in diameter. The transillumination becomes brighter as the bone is thinned.

Sometimes the aiming beam of the laser causes a strong reflection as it strikes the tissue. The site illuminated by the reflected beam may be mistaken as the intended operation site and vaporisation undertaken at a wrong site. In such cases, it is helpful to reduce the intensity of the aiming beam or to switch it off completely. The aiming direction is provided by the transilluminated beam in DCR, and the use of the aiming beam is superfluous!

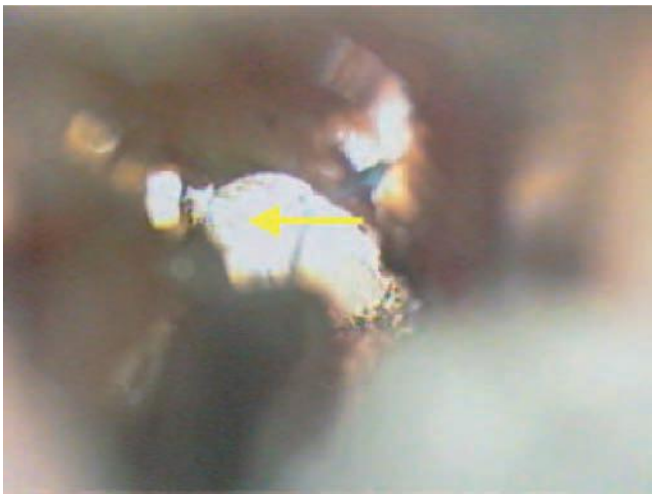


Fig. 11. Vaporisation of bone with Ho:YAG laser causes considerable flashing of visible light, but does not cause any thermal damage.

15.8. Creation of rhinostomy

The vaporisation is continued until an opening is created in the centre of the thinned-out bone. The bony opening is enlarged by continuing vaporisation until it is some five mm in diameter (Fig. 12).

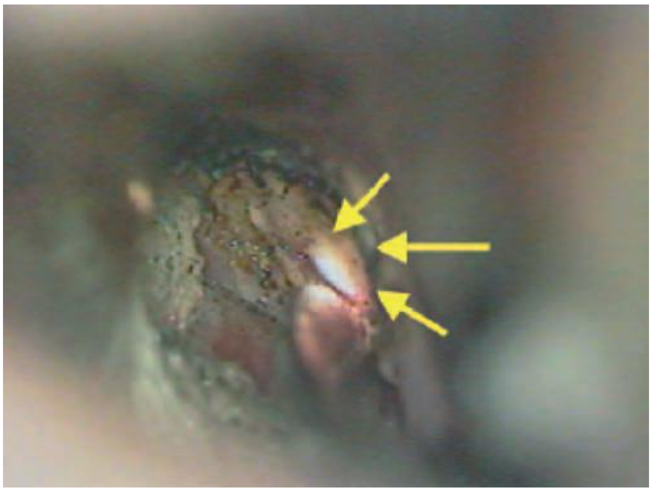


Fig. 12. The bony opening of the lacrimal fossa shown by Lempert elevator. The light pipe transilluminates the lacrimal sac.

The rim of the fistula is usually charred or reduced to ash. Continuing laser strikes fails to remove this tissue. It simply results in further dissipation of heat into the surrounding tissue. The rim is freshened by curetting or with reverse biting forceps (Figs. 13 and 14), specially designed by one of the authors (VO).

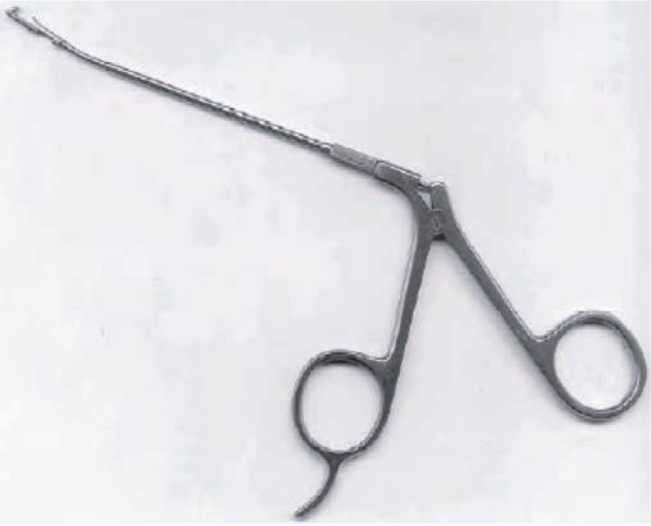


Fig. 13. Specially designed forward biting forceps to freshen the rim of the bony opening to reduce incidence of stenosis.

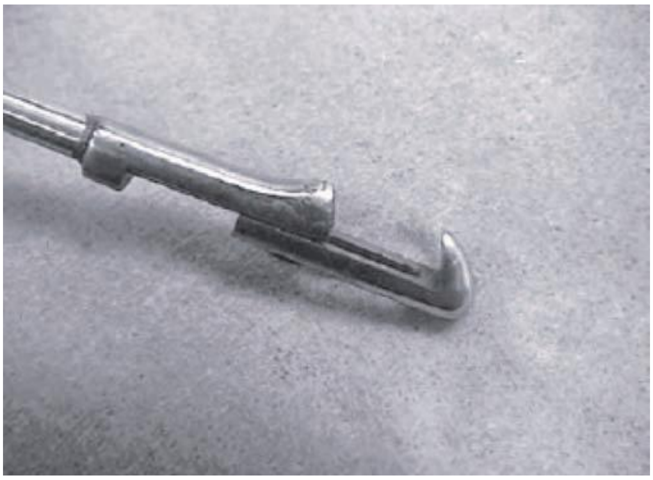


Fig. 14. Close up of forward biting forceps.

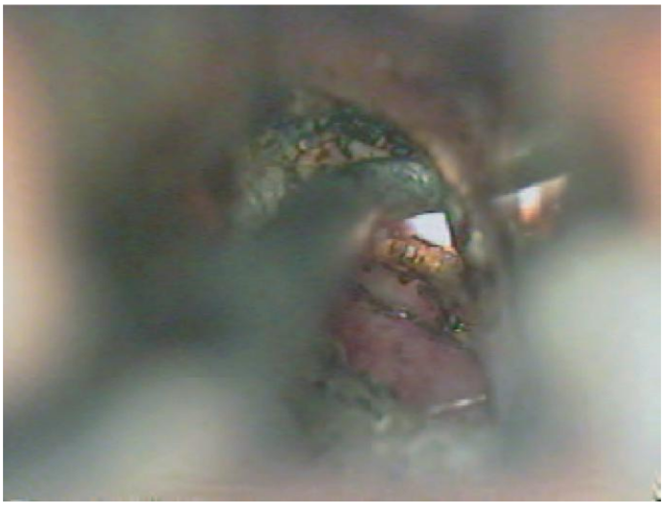


Fig. 15. Dundas Grant attic seeker in the lacrimal fossa. It severs any fibrous bands and separates the sac.

A blunt-angled probe, such as the Dundas Grant attic seeker (Fig. 15), is then inserted between the bony opening and the sac. Any fibrous bands are severed, and the sac is separated from the fossa by manoeuvring it. The mucosa of the lacrimal sac is then vaporised, thereby creating a fistula between the nasal fossa and the lacrimal sac. A specially calibrated measuring device is used to assess the size of the fistula in order to ensure uniformity. The steel ball can easily be felt when the lacrimal fossa is palpated just inferior and lateral to the medial canthus (Fig. 16a-f).

15.9. Flushing the system

The light pipe is then removed and the lacrimal system flushed with fluorescein in order to ensure its free flow into the nasal cavity via the fistula (Fig.

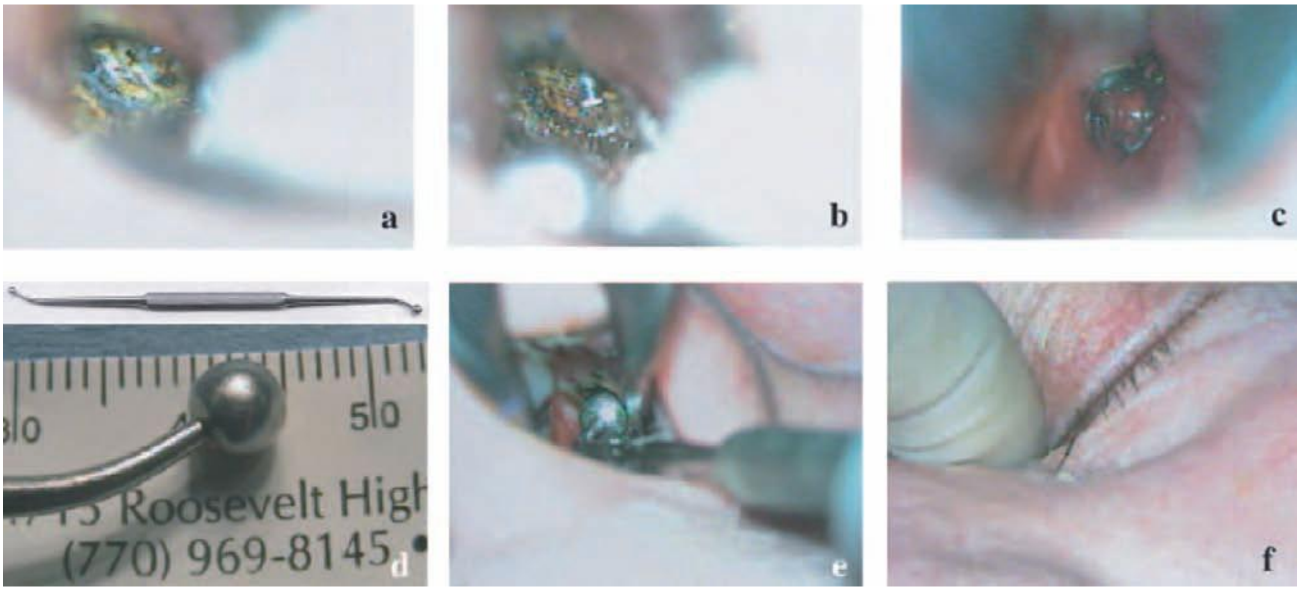


Fig. 16. a, b, c. Sac mucosa vaporised and sac opened. Light probe in the opening of the sac; d, e, f. The opening is measured with a metal probe (four mm one end, five mm other end). It can be felt under the skin infero-lateral to the medial canthus.

17). Forcible syringing should be avoided. If flushing is unsuccessful, this indicates additional proximal obstruction which was overlooked at the initial diagnosis. Repeated attempts at introduction of the light pipe may have resulted in damage to the canaliculus and syringing results in extravasation.

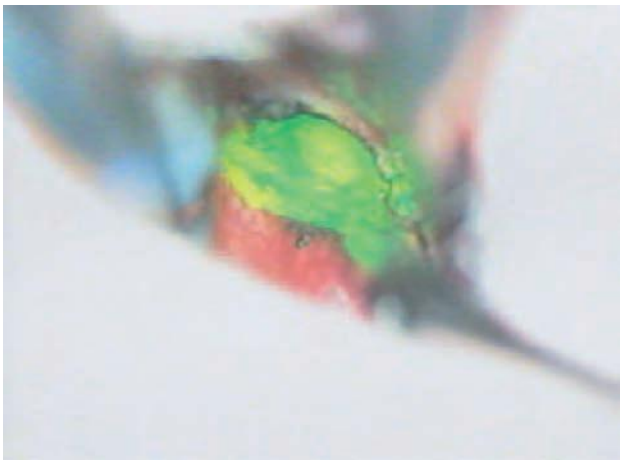


Fig. 17. The sac is flushed with fluorescein injected through one of the canaliculi.

16. Intraoperative risks with ENL-DCR

In the majority of cases, there are very few intraoperative risks and the procedure is fairly straightforward. Nevertheless, some are encountered, and these are described in the following sections.

16.1. Failure to locate transilluminated beam in the nasal fossa

The various factors have been described above under 10.4. In this section, some of the causes and their management are described below in detail.

In some cases, the beam from the lacrimal fossa may not be sharply transilluminated in the nasal fossa. One of the causes is the presence of mucocoele. The mucocoele is usually diagnosed preoperatively, and the bone is fairly thin on account of expansion. In the presence of a fair-sized mucocoele, introduction of a light pipe and its accurate positioning may be difficult due to the physical resistance of the mucocoele. In such cases, it may be possible to insert the pipe via the superior punctum. A few laser strikes usually result in the flow of retained secretions and help to localise the lacrimal fossa.

Transillumination is poor if the bone is very thick, in cases of dacryolithiasis, dacryomucocoele, and fibrosis of the lacrimal system, or following facial trauma. Surgery should then proceed with extreme caution and only by the endonasal, rather than the transcanalicular, approach (described below). Removal of bone, layer by layer, should result in the light beam getting brighter. If this cannot be accomplished, the operation should be abandoned.

16.2. Intra-operative bleeding

A major advantage of the laser is its ability to secure intra-operative haemostasis. Bleeding can occur intra-operatively, but it is rarely troublesome. It may come from the nasal mucosa, the vascular plexus surrounding the mucosal lacrimal duct, or the inflamed mucosa of the lacrimal pathways. Minor bleeding can be controlled with a few laser strikes in the defocused mode. Large-scale laser strikes to control bleeding result in gross tissue damage, marked inflammatory response, and a potential for synechiae. Any bleeding that is not easily controlled by a few laser strikes in the defocused mode should be controlled with the application of topical decongestants on pledgets.

Bleeding from the nasal mucosa due to instrumentation may be troublesome in some cases, but it can easily be controlled with decongestants. An enlarged and engorged anterior end of the middle turbinate can result in constant ooze, and requires alternate packing and laser strikes for the creation of a fistula. In chronic dacrocystitis, the lacrimal mucosa may be thick, resulting in bleeding. It is rarely of any significance, and can be controlled with pledgets soaked in decongestants.

16.3. Associated pathology

Access to the operation site may also be inadequate due to associated pathology such as a deviated nasal septum, polyps, concha bullosa, etc. The appropriate surgical procedure will be necessary and can be undertaken as a preliminary step at the time of performing DCR. A hypertrophied anterior end of the middle turbinate may obscure the operation site, and can be vaporised at the same time. The laser beam in a defocused mode can control any bleeding from the mucosa (Allen and Berlin, 1989).

17. Postoperative course

Following ENL-DCR, under either local or general anaesthesia, patients usually feel remarkably well, with no pain in the nose, or bruising of the eye – unlike after the external approach. They are able to go home within a couple of hours of surgery. Secondary haemorrhage is rare in ENL-DCR, whereas in EX-DCR it has been reported to occur in 5-10% of patients.

Topical steroid-antibiotic nasal drops are prescribed for six weeks. Antibiotics are not routinely prescribed, except in cases of frank pyocoele. The first review takes place after three to six weeks. Without the stent, slough covers the fistula within the first 48 hours. However, this clears up within ten days, and a healthy mucosal lining covers the bony opening. The fistula cannot always be detected as a distinct opening, and the operation site may show a slight dimple, or may appear completely normal.

18. Postoperative review

The patient is asked about the success of the surgery and the results are recorded. The site of the stoma is inspected. Usually, at the six-week review, there is no sign of any crusting at the site of operation. However, if crusting is present, no attempt is made to remove it. Flushing of the drainage system is avoided since this may produce iatrogenic trauma. The patient is either given a further appointment or is discharged. Figures 18a and b show the rhinostoma six weeks following Ho:YAG DCR. Pressure on the lacrimal duct produces fluid. The stoma is not always seen as a distinct entity. Sometimes it is covered by a thin membrane which moves synchronously with patient blinking. At other times, the healing is so perfect

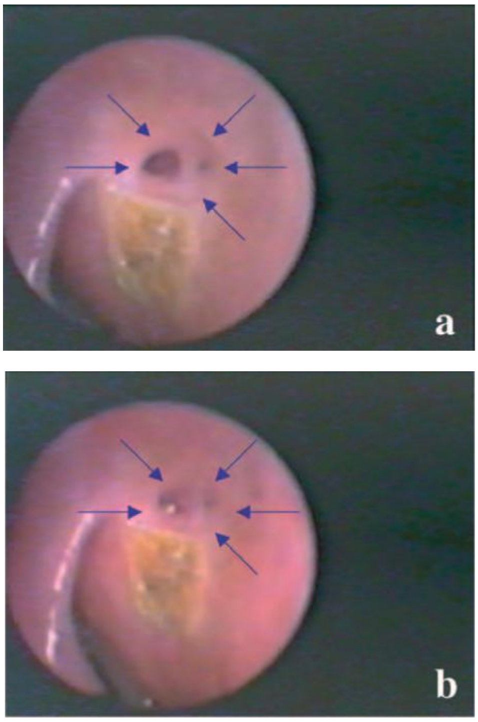


Fig. 18. a, b. The rhinostoma six weeks following Ho:YAG laser DCR. Pressure on the lacrimal duct produces fluid (b).

that there is no evidence of any scarring at all. The visual presence, the size, the appearance and the patency of stoma usually have no correlation to the successful surgical outcome with relief of patient's of epiphora.

19. Risks and benefits for the patient

In the majority of patients there are very few risks, and the procedure is associated with very low morbidity. As a rule, patients can go home the same day and can resume their work within a day or two, depending upon the risk factors due to general anaesthetic considerations. Below is a brief summary of some of the complications encountered.

19.1. Periorbital subcutaneous emphysema

In a personal series of 23 cases of transcanalicular DCR, one of the authors (PE) (Eloy *et al.*, 2000) encountered three cases of subcutaneous periorbital emphysema. This resolved spontaneously without any treatment within 24-48 hours. The complication occurred due to poor transillumination in the lateral nasal wall since the fibre was directed towards the orbit. Thus, it is necessary that no firing should be undertaken transcanalicularly, unless the transilluminated beam is sharp and bright.

19.2. Granuloma

Rarely, granulations or granuloma can form at the site of the fistula. These may obstruct the opening completely and cause recurrence of the symptoms. The most likely cause of granulation formation is a low-grade infection or a foreign body reaction to the stent if it butts against the rhinostomy site, promoting granulations. Its removal usually results in a satisfactory resolution. In a few cases, it is necessary to advise revision surgery for removal of the granulations and refashioning of the stoma. Antibiotic nasal and eye drops help reduce the incidence of granulations. The topical application of cytotoxic agents to minimise the incidence of postoperative granuloma/fibrosis is described below.

Beloglazov *et al.* (1998) reviewed 315 endonasal operations on the lacrimal duct with prolonged intubation. They found that the most frequent complication of these operations was the formation of granuloma, which affected the inferior lacrimal canaliculus. They postulate that this granuloma forms as the result of an allergic response to the tube material, and cite their histological findings in support of this theory. They suggest surgical removal with topical and systemic anti-allergic management. The offending object (the stent) is removed, and the site of granulation then heals with fibrosis. This work is interesting, not so much because of the allergy theory but because of the formation of granuloma in the inferior lacrimal canaliculus. Most of us record granuloma as a complication of lacrimal surgery, based on the visual evidence of granuloma at the site of the nasal opening. If an allergic reaction is going to take place, then it is not restricted to the site of the nasal opening. The whole mucosa of the ducts will swell up. Removal of the tube, together with anti-allergic management, is then the correct option. One of the authors (VO) believes that the formation of granuloma at the site of the nasal opening is probably a foreign body reaction.

The rhinostomy should be located as low as possible. High rhinostomy results in a sump syndrome (Fig. 19a and b), predisposing to recurrent infection of the sac and the duct. Sometimes, frequent massaging of the sac by the patient helps expel thick mucus and resolves the symptoms. The patient must be shown the precise location of the sac

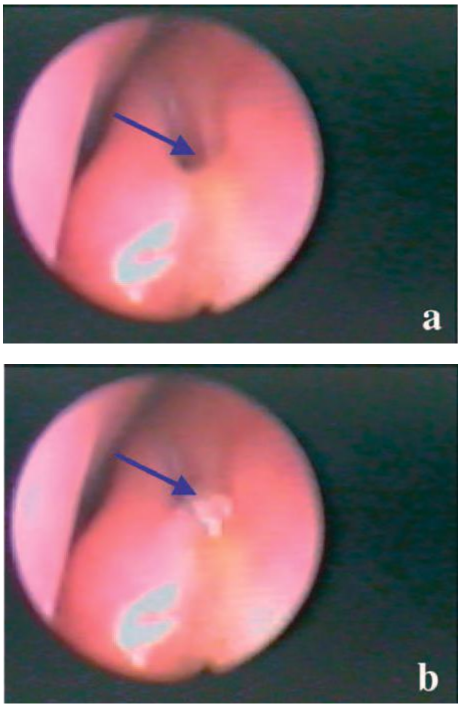


Fig. 19. a. The rhinostoma is obstructed in the lower half due to formation of synechiae; b. Pressure on the sac produces mucus.

for massaging. A little practice under the watchful eye of the surgeon will ensure the correct manoeuvre.

19.3. Stenosis of the stoma

In common with surgically created stoma in other parts of the body, rhinostomies also shrink. The nasal mucosa grows over the bony opening and may heal completely without any visible scarring. Nevertheless, in a number of cases the patient remains symptom-free. It is likely that a minute opening, not easily visible to the naked eye, could remain patent and continue to drain. After all, drainage of the tears is a much more dynamic process, effected by the lacrimal pump. The action of the pump is strong enough to push the tears through the puncta, which are much smaller than a surgically created rhinostomy of four or five mm. The purpose of creating a large rhinostomy is to allow for this shrinkage.

An alternative explanation for improvement of symptoms, even if no stoma is seen, is that the pathology responsible for the distal obstruction has resolved.

Whether the bony opening also closes almost completely over the passage of time is not known. Certainly, in revision cases following external DCR carried out a number of years earlier, it is the dense mucosal scarring rather than the bony closure that is so apparent.

In an interesting work, Ezra *et al.* (1998) monitored the size of the opening in the postoperative period following external DCR using B mode ultrasonography in order to define postoperative soft tissue anastomosis. Twelve patients undergoing 16 external DCRs, with the creation of large osteotomies, were recruited in a prospective study. The horizontal and vertical dimensions of the bony ostium were recorded during surgery and compared with the ultrasonographic dimensions of the soft tissue anastomosis at one day, two weeks, and six months after surgery. Functional patency was confirmed with dye testing and irrigation. The soft tissue anastomosis on the day after surgery was markedly smaller: compared to the bony opening of 235 mm^2, it had decreased to 144 mm^2. Since the soft tissue opening at the time of surgery cannot be larger than the bony opening, the reduction represents shrinkage of nearly 40%!

The soft tissue anastomosis continued to shrink to between eight and 208 mm^2 (mean, 98 mm^2; 68% of immediate postoperative value) at two weeks, and three-208 mm^2 (mean, 71 mm^2; 49% of immediate postoperative value) at six months. Fourteen of the 16 DCRs (88%) were functional at the end of the study, the two failures being associated with marked contracture of the soft-tissue anastomosis. The outcome of surgery correlated significantly with the area of anastomosis at two weeks ($2 = 16.0$, $p = 0.01$). Ezra *et al.* (1998) noted that B-mode ultrasonography provided a simple and effective method for assessing the size of the soft tissue anastomosis after EX-DCR and that there was a significant reduction in size after surgery, to which the functional outcome of surgery appeared to be related. They emphasised the huge importance of creating a large rhinostomy in the success of lacrimal surgery.

In most cases, the 'end point' of the operation (and, by implication, the size of the opening) is decided by the operator following his visual impression. If, according to Ezra *et al.* (1998) the functional outcome is closely related to the size, then some method of measuring the opening to obtain consistency may improve the results. One of the authors (VO) devised a simple angled instrument with a metal ball four mm in diameter at one end and five mm at the other. This ball is passed through the opening to measure its size. It is sometimes surprising that, when the opening seems adequate, on measuring it, it hardly allows the free passage of even a four-mm metal ball, let alone a five-mm one at the other end.

There are several reasons why the apparently wide stoma is deceptively inadequate. The opening in the sac is always one or two mm smaller than the bony opening. When the sac is opened, the margins retract out of sight. One author (VO) always requests the ophthalmic surgeon to use the light pipe to push any retracted or loose fragments of sac into the nasal fossa for vaporisation. In chronic dacryocystitis, the sac is thickened, and it is possible that the whole thickness is not effectively removed. Finally, some surgeons avoid doing any work on the mucosa of the sac under the erroneous impression that the sac will be traumatised and therefore stenosis will recur. This is a fallacy. It is true that any mucosal trauma to the delicate mucosa of the canaliculi must be avoided, and that here, handling should be very gentle. This is not so in case of the sac. Probing the inside of the sac is an essential part of the surgery. We have seen cases with sufficient frequency when mucoid discharge was only exuded after probing.

Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery, edited by V. Oswal, et al., Kugler Publications, 2014. ProQuest Ebook Central,

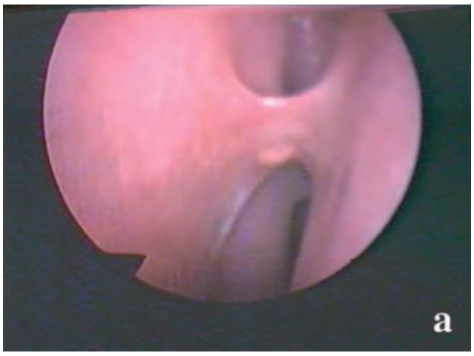
Mucocoeles may thus be loculated and only a good probing will exteriorise them.

The rim of the soft tissue opening is devitalised with the thermal effects of the laser. Its manual removal will lessen the inflammatory response and reduce the rate of re-stenosis. One author (VO) uses a specially designed punch forceps to remove the narrow band of charred and devitalised bony and soft tissue from the rim of the rhinostoma. Initial impression indicates an improvement in success rates. In fact, in a number of cases, a patent opening is seen to discharge the secretions or to tear on blinking. In general, wound toilet at the end of the surgical procedure is an essential integral part of laser surgery. It is simply carried out by suction, and by wiping the bed of the operation site with wet ribbon gauze.

Stenosis of the surgical opening is more frequent in transcanalicular-DCR (TC-DCR) than in ENL-DCR, due to the relatively small size of the opening and its posterior location.

19.4. Synechiae

Formation of synechiae is not uncommon in nasal surgery. Synechiae form due to damage to the mucosa of adjacent surfaces (Fig. 20a). This damage may result from instrumentation or from the spread of thermal energy to the surrounding non-target structures. Synechiae usually form between the lateral surface of the middle turbinate and the medial surface of the lateral wall of the nose. They may in fact obstruct the opening and result in failure of the procedure. Their occurrence is more common in cases of narrow nasal fossae, large concha bullosae, chronic pathological conditions of the nasal mucosa, etc. Some synechiae are symptomatic, while others are not. If symptomatic, revision surgery is necessary. Synechiae are more frequent after ENL-DCR compared to after TC-DCR. One of the authors (VO) routinely covers the lateral surface of the middle turbinate with wet ribbon gauze (Fig. 20b). The use of the gauze also ‘opens up’ the narrow space between the lateral surface of the middle turbinate and the lateral nasal wall, and improves access.



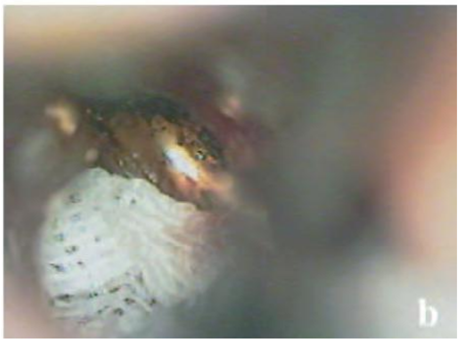


Fig. 20. a. Synechiae form due to damage to the mucosa of the apposing surfaces; b. Protection of lateral surface of middle turbinate with wet ribbon gauze.

19.5. Migration of stents

An excessively tight stent may cut through the canaliculus as well as the skin overlying the canaliculus. The raw surfaces heal with a web, which buries the stent. This usually results in scarring or loss of the pump system, which leads to failure of drainage of tears. The stent can be retrieved in the nose by cutting one of the tubes that forms the loop before the sleeve.

20. Sequelae

In common with our own experience, cases of long-term sequelae are extremely rare and none have been reported in the literature.

21. Variations in standard procedures

The success rate following the so-called standard endonasal laser procedure described above is reported to be between 65 and 80%, depending upon the criteria used by various workers (Table 3). In an effort to improve the success rate, various modifications have been introduced. A number of variations has been reported, according to the preference of individual surgeons. One such major variation is Transcanalicular dacryocystorhinostomy (TC-DCR), in which the optical fibre carrying the laser beam is passed through the canaliculus.

Table 3. Laser-assisted endonasal DCR – review of literature.

Authors	*Cases*	*Technique*	*Results*
Metson	46	END/Hol-Yag	85%
Pearlman	46	END/Nd:Yag	85%
Reifler	19	END/KTP	68%
Eloy	20	END/diode	85%
Mickelson	19	END/KTP	80%
Piaton	422	END/Diode	91,94%

22. Transcanalicular-DCR (Fig. 21)

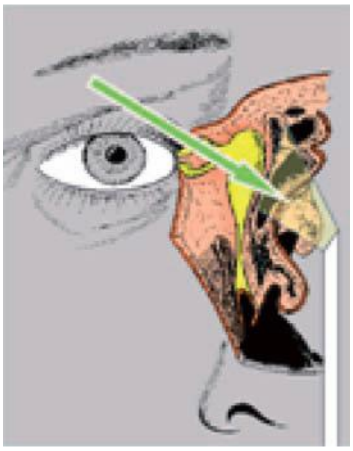


Fig. 21. Transcanalicular laser DCR.

This approach was described in 1992 simultaneously by Levin and StormoGipson, and Christenburry, and was used almost exclusively by ophthalmologists (Rosen *et al.*, 1997; Silkiss *et al.*, 1992; Adenis *et al.*, 1996; Dalez and Lemagne, 1997). The technique was first reported in the English literature in 1992 (Levin and StormoGipson, 1992) and in the French literature in 1994 (Piaton *et al.*, 1994; Adenis *et al.*, 1996; Dalez and Lemagne, 1997). Recently, some reports of this procedure also appeared in the otorhinolaryngology literature (Saint Blancat *et al.*, 1996; Mazeas and Ouairy, 1999; Eloy *et al.*, 2000).

The transcanalicular method (Fig. 22a-d) consists of introducing the laser fibre, with its visible or aiming beam, into the canaliculus. It is then advanced in the same way as the light pipe. A 600-µm fibre is preferable as the 800-µm fibre is too large and unyielding, and may damage the mucosa of the canaliculus. The 400-µm fibre does not have adequate rigidity and may break in the canaliculus. Accurate positioning is confirmed endonasally. The therapeutic beam is then activated to create an opening from the sac side into the nasal fossa (lacrimal sac > bone > nasal mucosa). One author (PE) used the diode laser for TC-DCR, with a power setting of 10 W in order to ensure that it only perforates and enlarges the desired area of bone. The stoma is fashioned and enlarged under direct vision by firing individual pulses of low energy in a rosette pattern.

While in theory this approach seems elegant and logical, in practice there are some technical problems. The fibre must be at least 600-µm in diameter in order to have some rigidity for its passage. Should there be a leak in the fibre as it lies in the canaliculus, the escape of energy would damage the delicate lining, and the intensity of the laser energy delivered by the fibre would decrease dramatically.

As noted under paragraph earlier, the bony nasolacrimal canal extends along the lateral nasal wall, downward and posteriorly by about 15°. Thus, there is a natural tendency for the fibre to go posteriorly in the direction of the orbit. Injudicious strikes of laser energy, without endoscopic control, would almost certainly result in ablation of the posterior-medial wall of the sac and entry of the fibre into the orbit, resulting in damage to the orbital contents. Follow-up examinations of the cases of transcanalicular approach showed a more posterior position and smaller diameter of the stoma than with the traditional endonasal approach described by Rouvier (Rouvier *et al.*, 1981; El Khoury and Rouvier, 1992). The stoma is usually located in the posterior part of the lacrimal ridge where the bone is thinnest. The stoma is relatively small and, therefore, stenting is obligatory with this method.

In order to avoid inadvertent entry into the orbit, Mazeas and Ouairy (1999) used a combined approach, whereby initial localisation is achieved via the transcanalicular approach and completed by the endonasal procedure.

In our hands (PE) the technique shows a success rate of 65% (Table 4). Revision surgery showed purulent discharge in the lumen in seven out of eight procedures. The rhinostomy had closed in all cases. One case had laser thermal trauma of the lower canaliculus.

The most likely cause is a small-diameter stoma resulting from the transcanalicular approach alone. Review of the literature (Table 5) shows a wide range of success via the transcanalicular route (PE). It can be explained by the selection of patients: the more distal the obstruction, the higher is the success rate.

Yet another factor must be considered. The laser fibre only works in a straight line. The lacrimal

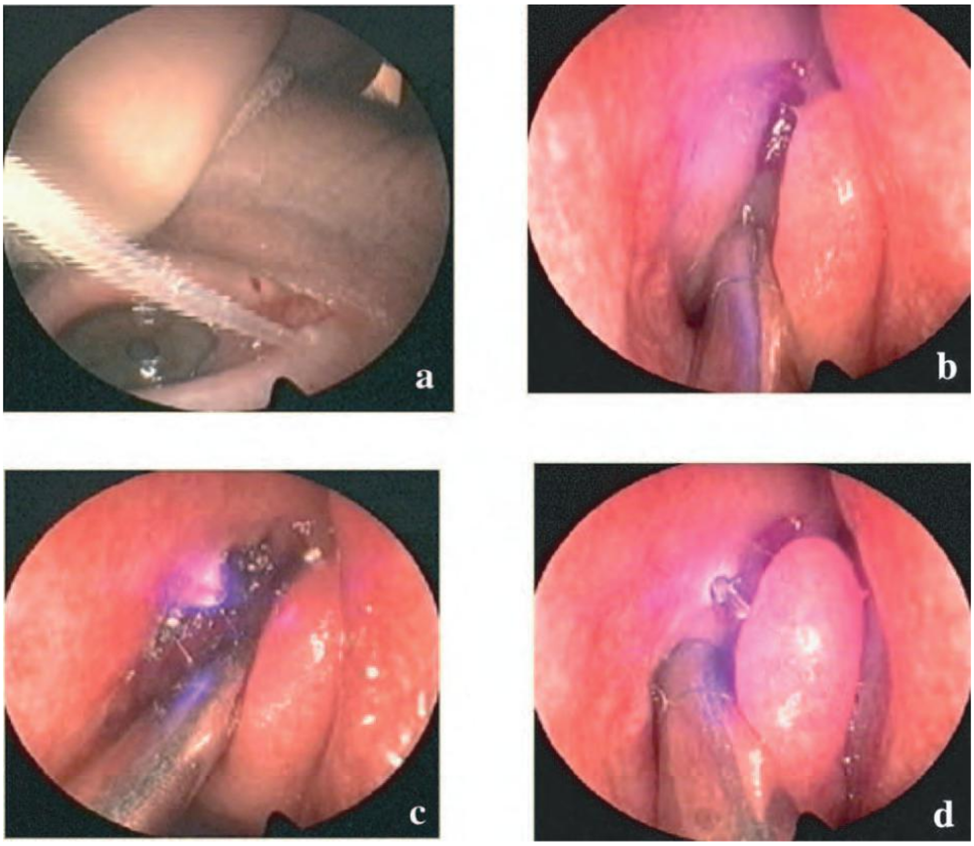


Fig. 22. Transcanalicular laser DCR with diode laser. A. A 600-µm fibre is inserted into the lower canaliculus; b. The accurate positioning is confirmed endonasally; c, d. An opening from the sac side into the nasal fossa (lacrimal sac > bone > nasal mucosa) is made.

Table 4. A, B. Review of success rate by transcanalicular laser approach based on presence or absence of discharge in the lacrimal lumen. In the group of patients without secretion there were four failures out of ten procedures, whereas in the group of patients with secretation there were six failures out of 19 procedures. The relative success rate in each group was 40% and 31.6%, respectively. The overall success rate was 65%.

Laser assisted transcanalicular DCR
(TLDCR)

From June 1997 to February 2000
26 patients: 22 women – 4 men
Average age: 61 year (19-79)
Average age women: 60.5 year (19-79)
Average age men: 65.5 year (48-78)
29 TLDCR: 3 bilateral – 16 R – 7L

Indications: 19 obstruction with secretion
10 obstruction without secretion

Succes rate: 17+2 /29 ➡ (65,5%)
Failure rate: 10/29 ➡ (34,5%)
➡ Endonasal REV surgery: 8/10
- ☐ Pus: 7/8
- ☐ Fibrosis: 1/8
- ☐ Lower canaliculus injury: 2/8
- ☐ Cauterisation of the lower canaliculus: 1/8

Literature: succes rate: 47% – 85%

Table 5. Review of literature: Outcomes following transcanalicular laser DCR.

Authors	*Year*	*N*	*Laser*	*Success*
Christenbury	1992	12	Argon	50%
Piaton	1994	41	Nd: YAG	75%
Lemagne	1996	26	HO: YAG	47%
Patel	1997	24	Nd: YAG	46%
Pearman	1997	34	Nd: YAG	85%
Rosen	1997	14	Nd: YAG	64%
Woo	1998	6	Nd: YAG	83%
Kuchar	1999	19	Er. YAG	84%
Eloy	2000	29	Diode	59%
Caversaccio	2001	12	Erbium	75%
Hong	2005	102	Nd: YAG	81%
Henson	2007	40	Diode	87%
Maeso & Selares	2007	150	Diode	92%
Plaza	2007	25	Diode	88%
Cintra	2008	32	Diode	89%
Narioka	2008	13	Diode	80%
Drnovsek-Olup	2010	122	Diode	83.3%

prominence comprises of two bones: the frontal process of the maxilla which is very anterior and thick, and the lacrimal bone, which is posterior and very thin. Typically only the lacrimal bone can be easily perforated with the laser. The energy needed to do it is rather low.

The frontal process is usually not reachable with this technique. And even then, a very high energy is needed to ablate it. This leads to great deal of carbonisation, much more thermal damage into the deeper layers, crust formation, granulation formation and a higher incidence of stenosis due to fibrosis.

Yet another factor is a stenosed surgical opening when the healing process is complete. To address this issue, Metson (1993) and Basmak (2010) proposed use of a drill to widen the stoma endonasally. Basmak reported the following results: Final anatomical success rates were 27/38 for group 1 (endocanalicular laser DCR) and 39/42 for group 2 (endocanalicular laser DCR + concomitant endonasal surgery) ($p = 0.02$). Final functional success rates were 25/38 patients in group 1 and 36/42 in group 2 ($p = 0.07$).

Thus, there does not appear to be any particular overriding advantage in transcanalicular use of the fibre, without simultaneous endoscopic monitoring and enlargement of the rhinostoma.

22.1. Mucosal flaps

Some surgeons advocate stitching mucosal flaps into position at the end of the operation in order to ensure long-term patency. This step is particularly difficult and tedious if undertaken endoscopically, and does not seem to influence the outcome (Becker, 1988).

22.2. Avoidance of stenting

While in theory, stenting seems to be a sound concept, there is doubt as to whether it influences the outcome (Griffiths, 1991; Jordan and Nerad, 1987). The stent may cut through the canaliculus and become buried under the skin of the inner canthus. The nasal end causes crusting, or even granulations, which lead to low-grade infection. However, in revision cases, which present with heavy scarring at the site of the operation, stenting appears to have a role.

Unlu *et al.* (2000) performed endoscopic DCR with cold instruments on 21 sides of 18 patients with chronic epiphora. No silicone tubing was used in any of the cases. Although no specific surgical measures were taken to ensure patency, in the postoperative healing period, the rhinostomy opening was maintained by means of the frequent removal of debris and the use of eye drops. The patients were evaluated by the fluorescence test and endoscopic control. Symptomatic improvement was achieved in 19 of the 21 sides (90.5%) and the results were confirmed by the fluorescein test under endoscopic control.

One author (VO) has not used stenting for the past three years in over 80 cases of DCR performed with the Ho:YAG laser. The surgical outcome was comparable to his own previous cases when stenting was used.

The complications from stenting are described earlier. Therefore, it is advisable to avoid routine stenting (VO). However, some authors advocate stenting when there is heavy scarring from previous operations, intraoperative difficulties leading to much manipulation of tissues, and revision endonasal surgery. The stent should be secured with a loose knot or a Watzke sleeve rather than a metal clip, in order to avoid foreign body reaction and subsequent granuloma formation, leading to fibrosis.

22.3. Combined laser and cold-instrument surgery

The closure of the rhinostomy (in some cases leading to failure of the EL-DCR) is probably dependent upon the surgical tool used. Compared to the use of lasers, cold-instrument surgery may not result in fibrous tissue formation. This may possibly result in better outcome following cold-instrument EN-DCR. Friesen *et al.* studied a bony healing with cold instruments and lasers. Tibial osteotomy defects were created in four groups of six rats each using the following: (1) #6 round bur with simultaneous saline irrigation; (2) CO_2 laser with char layer intact; (3) CO_2 laser with char layer removed; (4) Nd:YAG laser with air/water-surface cooling, and char layer intact; (5) Nd:YAG laser with air/water-surface cooling, and char layer removed; and (6) Nd:YAG laser without air/water-surface cooling, and char layer removed. Progressive healing from day 0 through day 21 post-treatment was observed in all treatment groups. However, compared to controls treated by rotary dental bur, those specimens treated by laser, regardless of laser type, energy density, or other parameters, exhibited a delay in healing that appeared to be related to the presence of residual char in the osseous defect. Specimens treated with the Nd:YAG laser using an air/water-surface coolant exhibited a decreased thickness and continuity of the char layer and yielded the only specimens with new bone formation at the surface of the laser ablation defect. In addition, the normal pattern of bone remodelling in the rat tibia appeared to have been altered by laser irradiation. They concluded that laser-induced osteotomy defects, when compared to those prepared by rotary bur, exhibited a delayed healing response that appeared to be related to the presence of residual char in the osseous defect.

Buchelt *et al.* (1994) studied the effect of Er:YAG and Ho:YAG laser osteotomy on bone healing. Sixty-nine male Sprague-Dawley rats were divided into three groups of 23 animals each and osteotomies were performed in group 1 with a power saw, in group 2 with the Er:YAG laser, and in group 3 with the Ho:YAG laser. Two animals of each group were sacrificed one week, four, eight, and 12 weeks after operation for histology investigation, and five animals of each group at four, eight, and 12 weeks after osteotomy for torque testing. All tibiae osteotomies with the Ho:YAG laser (group 3) developed pseudoarthrosis within 12 weeks and, therefore, torque testing could not be performed for this group. Biomechanical measurements of bone treated by power saw or Er:YAG laser osteotomies, respectively, showed no significant statistical difference in the stability of bone between the two groups. Histology examination after one week exhibited fibrous tissue at the site of osteotomy in rats of all three groups and additionally carbonisation in rats of group 3. Saw osteotomies resulted in more callus formation than Er:YAG osteotomies, but both techniques resulted in bony reunion within eight weeks. Ho:YAG laser-treated osteotomies, however, exhibited formation of dense fibrous tissue, carbonisation and no callus formation within 12 weeks.

One author (PE) avoids the transillumation technique altogether, on the basis that any manipulation of the delicate canaliculi may result in iatrogenic trauma and fibrosis, leading to an unsuccessful outcome. He starts the procedure by vaporising a five-mm-wide and 1.5-mm long strip of mucosa covering the lacrimal bone, just superior to the inferior turbinate attachment. The bony wall of the canal is then thinned with the laser. Removal of the bone is completed using cold instrumentation, such as the bone punch. Part of the duct and the sac are laid bare, and incised with cautery to avoid bleeding. The system is flushed with saline tinted with methylene blue and the procedure is completed without stenting (Eloy *et al.*, 2000). Following the procedure, this author was able to claim improved short-term results with an 80% success rate.

Another author (VO) uses a similar combination.

However, using the Ho:YAG laser, he vaporises the nasal mucosa over a much wider area of six to seven mm. The debris and any loose strands are removed by mopping with ribbon gauze. The bone covering the sac is then gradually thinned, and the products of laser strikes are periodically removed by wiping with gauze. Ablation is continued until the sac is exposed. The margins of the bony opening are then removed with specially designed reverse biting forceps until a five-mm opening is achieved. A Dundas Grant attic seeker is inserted into the stoma to ensure that there are no fibrous bands or pocketing of secretion. The sac is then opened by vaporising it with the laser.

The size of the opening is measured with a measuring probe, and the system is flushed with fluorescein. Wound toilet is carried out by removing any debris with suction, and wiping with wet gauze to discourage healing by fibrous tissue. No stent is used. The initial results suggest a success rate of 89%.

Another author (NJ) used the Ho:YAG laser for his first 800 cases and has used the KTP Star pulse for the last 250 cases. All procedures were undertaken under local anaesthesia using a light pipe to define the site for creating a rhinostomy. In his hands, this technique proved excellent for patients unfit for general anaesthesia. Other indications include patients receiving anticoagulant therapy, those who wish to avoid an external scar, and revision surgery. The author found that not using the stent reduced the success rate. In his opinion, scar formation is greater in laser cases when compared to cold instrument endonasal DCR. However, the non-laser endonasal procedure takes much longer and usually requires a general anaesthetic. In comparison, ENL-DCR is a relatively minor procedure taking an average of 22 minutes, including administration of the local anaesthetic. His success rate is approximately 75% at 18 months for all patients, including some with a minor degree of proximal obstruction. These results are based on individual follow up. Patients lost to follow up were not included and were counted as successes. Significant rates of late stenosis can occur up to 18 months (Herar *et al.*, 1997; Sadiq *et al.*, 1997; Bakri *et al.*, 1998).

23. Laser-assisted dacryoplasty

Dacryoendoscopy allows direct visualisation of the intraluminal mucosa and the patency of the lacrimal drainage system. Diagnostic dacryoscope has a diameter of 0.9 mm whereas therapeutic dacryoscope has a working channel with the overall diameter of 1.1 mm. (Figs. 6, 23 and 24) The working channel can be used to insert a 200-micron fibre to undertake laser vaporisation of any obstruction to drainage by way of fibrous bands, post-operative adhesions, thickened mucosa, etc. This technique is also particularly useful in dealing with canaliculus or common duct pathology. The laser ablation is limited to the mucosal pathology and is not intended to create a bony rhinostome. The diode laser, the KTP laser or the Er: YAG has been used to vaporise the mucosa. The power setting is very low (three to five watts), so as not to perforate the bone.

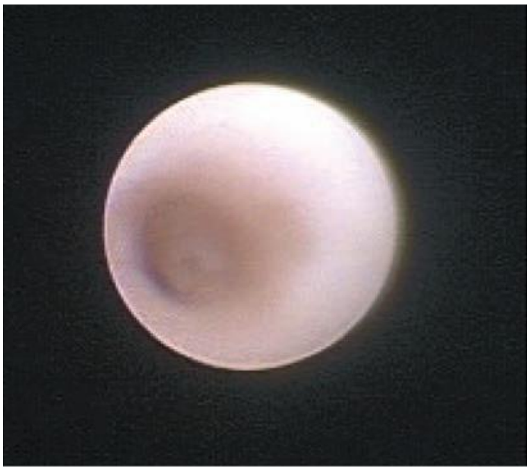


Fig. 23. Visualisation of the lumen of the inferior canaliculus.

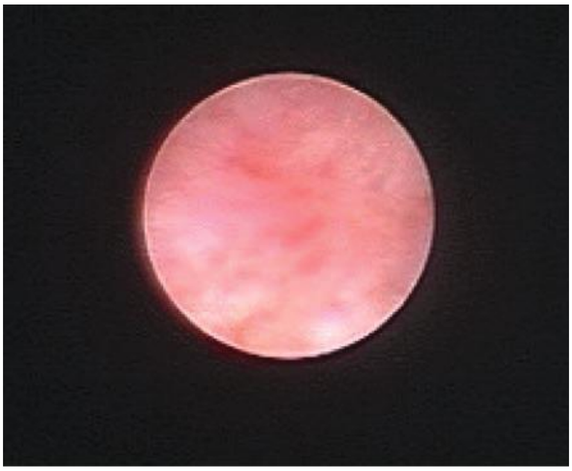


Fig. 24. Visualisation of the lumen of the lacrimal sac-notice the colour and the shape like a bladder.

A bicanalicular stent is typically left in place for three to six months. The overall success rate is about 75%- 80% for primary surgery and about 85% in case of surgery for failures after external or endonasal DCR (Mullner, 1999; Hofman, 2003; Hong, 2005). Topical application of Mitomycin-C may additionally help reduce fibroblastic reaction (Henson, 2007).

Dacryoscopic laser ablation can be used in combination with endonasal approach to increase the success rate as has been demonstrated by Georg von Arx in 2003.

24. Antimitotic application

Some workers (Camara *et al.*, 2000; Yeatts and Neves, 1999) advocate mitomycin-C (MMC; an antimitotic agent), often used in ophthalmological procedures to reduce scarring and formation of adhesions following surgery, in order to discourage the formation of fibrosis.

24.1. Review of the literature

Several papers have appeared in the literature recently which used MMC to improve the results of DCR procedures.

Hu *et al.* (2000) studied the effect of the brief exposure of MMC (0.1-0.4 mg/ml) for one to five minutes on cultured human nasal mucosa fibroblasts. A portion of the fibroblasts survived the mitomycin treatment and showed evidence of regrowth within two to three days. These cells reached confluence after five to seven days. The inhibition rate using MTT assay of 0.4 mg/ml MMC for five-minute exposures was 31.3%. A dose-response effect was noted with lower concentrations and shorter exposure times when the inhibition rates were lower (but not significantly so). DNA fragmentation was observed in fibroblasts 24 hours after MMC exposure (0.4 mg/ml) for five minutes, compared to normal controls. The apoptotic rate of fibroblasts treated by 0.4 mg/ml MMC was significantly higher than in the controls ($p < 0.05$). Hu *et al.* concluded that short MMC exposure times have a variable cytotoxic effect and inhibit proliferation of cultured nasal mucosa fibroblasts. MMC also can induce apoptosis with a five-minute exposure time. They concluded that MMC has a complex effect in DCR. You and Fang (2001) assessed the efficacy of intraoperative MMC in EX-DCR in 46 cases (50 lacrimal drainage systems (LDS). The patients were randomised into three groups. In the control group, a standard EX-DCR procedure was performed. In the two MMC groups, a piece of cotton soaked with 0.2 mg/ml MMC (group 1) or 0.5 mg/ml MMC (group 2) was applied to the nasal mucosa and to the mucosa of the lacrimal sac in the osteotomy site for five minutes. In all patients, DCR was patent by irrigation two to three weeks postoperatively. After a mean follow-up interval of 35.2 ± 5.3 months, DCR was still patent in 15 patients, providing strong support for the use of intraoperative MMC.

Gonzalvo Ibanez *et al.* (2000) carried out clinical and anatomical evaluation with helical CT (HCT) in 17 patients who had undergone DCR. The patients were randomly assigned to either a control group (eight patients) or an MMC group (nine patients). Intra-operative MMC (0.2 mg/ml/ 2 minutes) was applied to the osteotomy site. HCT scans were performed within 24 hours after surgery and then at one, three, and six months. Epiphora grade and lacrimal drainage system irrigation were evaluated after surgery. Computer-aided, three-dimensional and multiplanar reconstruction was used to calculate the surface area of the osteotomy site. The mean follow up was 10.47 ± 4.1 months (range, 6-18 months). All patients in the MMC group remained asymptomatic, producing a 100% result. The result in the non-MMC group was 75%. At the end of the sixth postoperative month, osteotomy size compared to that immediately after surgery was 93.82 ± 4.55% in the MMC group, while it was only 64.81 ± 9.68% in the control group ($p < 0.001$). Statistically significant differences were noted at one, three, and six months. They concluded that intraoperative MMC may increase success rates over the traditional DCR procedure and is effective in reducing the closure rate of osteotomy after DCR.

Zilelioglu *et al.* (1998) reviewed the results of the topical application of the wound healing inhibitor MMC in 40 eyes of 39 patients undergoing cold-instrument surgery for DCR. Fourteen cases had primary surgery for epiphora, while 17 had revision surgery for a previously failed external DCR. MMC was applied to the ostium. The postoperative follow-up period was nine to 27 months (mean 18.2). The success rate of endoscopic DCR with intraoperative MMC was 77.3%, while the success rate without MMC was 77.8%. Statistical analysis did not show any difference between the two groups with regard to ostium size and success rate.

Selig *et al.* (2000) reported improved results of endoscopic DCR performed with the intraoperative topical application of MMC. The procedure was successful in seven of eight instances, with a follow-up of three to 27 months. In one procedure, obstruction recurred ten weeks after surgery.

Yeatts and Neves (1999) applied MMC (0.3 mg/ml for three minutes) topically to the fistula site in eight patients undergoing revision DCR for membranous failure. All patients remained asymptomatic, and anatomical patency was confirmed by probe and irrigation, after a mean follow-up period of 14.6 months (range, six to 26 months). No postoperative complications associated with the use of MMC were observed. They concluded that, in patients who do not maintain a patent fistula after DCR, due to membranous occlusion of the rhinostomy site, the adjunctive use of MMC may increase the success rate of repeat DCR.

The salient points in respect of MMC are:

- The effect of MMC on fibrocyte and fibroblast populations is dose- and time-related;
- None of the workers encountered any complications from the topical use of MMC;
- The work of Yeatts and Neves (1999) suggests MMC's effectiveness in revision cases, while other workers recommend its use in primary cases as well as in revision cases;
- All the work noted above relates to the use of external and endoscopic cold instrumentation.

Is the effectiveness of topical application different when laser technology is used? One author's (NJ) experience in the use of MMC did not prove as successful as some of the work associated with cold-surgery instrumentation. It may be that the cells in the periphery of the fistula have suffered thermal damage and, therefore, the absorption of MMC is much less than when the procedure is carried out with cold instrumentation. The extent of the zone of thermal damage depends on numerous factors covered in this chapter. Perhaps the effectiveness of MMC will increase in 'laser' cases if the devitalised rim is removed with cold instruments and then MMC is applied (VO).

The use of topical 5-FU, which inhibits cells from proliferating rather than being cytotoxic, may reduce the amount of mucosal scar tissue which is the commonest cause of failure. In one author's (NJ) departments, a prospective randomised trial showed a benefit of almost 10% after one year in patients in whom topical 5-FU had been applied to the rhinostomy site for five minutes. However, multi-variate analysis failed to support the initial apparent improved success rate due to 5-FU application. Interestingly, Fezza *et al.* (1999) reported cases of punctal and canalicular stenosis leading to symptoms of tearing in patients undergoing 5-FU therapy administered systemically for cancer treatment. They noted that, while some patients receiving 5-FU have resolution of their tearing with cessation of the drug, many other patients required surgical treatment of their lacrimal outflow system.

25. Outcome measures

Although the surgical steps are standard, there are a number of factors that influence the outcome.

25.1. Learning curve

When compared with EX-DCR, endoscopic DCR requires skill in the use of an endoscope in a confined space. There is a definitive learning curve for the novice in endoscopic nasal surgery, with or without a laser. Surgeons with previous experience in the endoscopic FESS procedure will master the technique quite quickly. The less experienced should attend peer training, courses, or obtain cadaver experience where possible.

25.2. Availability of equipment and instrumentation

Some lasers are better at bone ablation than others, *e.g.*, the Ho:YAG is a good bone ablator, reducing the bone to white ash rather than charring it. On the other hand, the CO_2 laser causes heavy carbonisation; its delivery to the target site is via a waveguide, which reduces the available power to 60 or 70%. Carbonisation heats the tissue to a high temperature, which increases the products of thermal destruction. The inflammatory process is intense, with repair by fibrous tissue. The Ho:YAG laser causes more 'splattering' of blood and collateral thermal injury than the KTP, although there does not appear to be a difference in the surgical outcome.

25.3. Technical difficulties

There are a number of technical difficulties. Individually, they may not amount to much, but cumulatively, they increase the iatrogenic trauma to the lacrimal system with adverse effects. They are:

- *Narrow punctum:* repeated dilatation may be needed before the light pipe can pass through it. Any trauma to the punctum and the canaliculus will lead to failure, adding another dimension to watering of the eyes.
- *'Soft stop':* in a number of departments, it is usual for the nurse practitioner to undertake flushing of the system in order to test its competency. Sometimes, the expertise of these nurse practitioners does not extend to cases that have canalicular or common duct pathology. Therefore, it is necessary for the surgical staff to ensure that they have tested every case personally and the diagnosis confirmed.
- *Poor surgical access:* a deviated nasal septum, enlarged anterior end of the middle turbinate, shallow middle meatus, and the presence of extensively pneumatised ethmoidal cells, are some of the causes that may require correction.
- *Bleeding:* it is unusual for anything other than minor bleeding to occur during EN-DCR. However, the enlarged anterior end of middle turbinate may be vascular and bleed with instrumenta-tion. Local or systemic disease can affect the mucosa. For example, cystic fibrosis, chronic rhinitis, sarcoidosis, polyposis, etc., will affect the outcome adversely (Fergie *et al.*, 1999). In a recent prospective study by a team of one author (VO), in 31 procedures, only 22 patients showed improvement (71%). A detailed study of the nine failures was carried out. The result is shown in Table 6.

Table 6. Analysis of failed cases.*

Case #	*Reason for failure*
1	Heart transplant, antirejection medication
2	H/o polypectomy, i/n ethmoidectomy
3	H/o polypectomy, i/n ethmoidectomy
4	Very small punctum
5	Nasal polyp
6	Marked DNS
7	Cause not apparent
8	Cause not apparent
9	Cause not apparent

* From: V. Oswal, U. Kumar, North Riding Infirmary, Middlesborough, Cleveland, UK (unpublished data).

Six patients had an abnormal contributory finding which may have influenced the outcome. In view of this experience, better selection criteria need to be applied. In the present study, applying better criteria, if we exclude those cases which are predisposed to failure, the number 'n'is reduced to 25 (31-6 = 25). The remaining three did not show any predisposing local or systemic disease and were considered to be true failures. The overall adjusted figure shows 25 procedures, three of which failed. This gives a success rate of 25 minus three, or 88%.

Although the surgical procedure is more or less standardised in an individual surgeon's hands, the outcome varies. Some patients obtain immediate relief even if a stent is used. In these cases, the tears must drain along the side of the stent by capillary action. However, others with stents do not show improvement until the stent is removed. Thus, it is necessary to assess the outcome after a period of three months following removal of the stent.

When no stent is used, patients usually obtain immediate relief within days of the operation when the oedema (if any) from the operation and the instrumentation subsides. If there is no immediate relief within a few days of the operation, the diagnosis should be revised and other causes sought for the epiphora. One author (VO) follows a policy of advocating revision surgery only in those cases that showed initial improvement followed by recurrence of symptoms. If symptoms do not improve, even for a few days immediately following operation, then the diagnosis must be revised, provided the operation was standard and that there were no technical difficulties.

25.4. When to assess the results

The timing will depend upon whether a stent is inserted or not. When no stent is used, some ophthalmic surgeons irrigate the system with saline solution 24 hours after the procedure. In the early postoperative period, the stoma is covered by slough. Ideally, removal of slough will discourage any stenosis. However, in practice, this is seldom possible on account of angulation of the stoma. Likewise, flushing the system is of little value for maintaining patency, and may be positively discouraged, because of additional trauma to the lacrimal canal system while it is recovering from operative trauma. If a stent has been used, watering may continue, at least in some patients. Therefore, it is logical to assess the patient for the first time at six weeks after surgery, and then at three months to remove the stent. Long-term follow up is of course necessary for assessing the success rate of the laser procedure. If the stoma is going to stenose, it will often do so by three months after removal of the stent, and the patients will have had recurrence of symptoms. However, late stenosis can occur up to three years after surgery, although most occurs in the first 18 months (NJ). A physiological method for assessing the patency of the stoma consists of putting fluorescein into the conjunctiva without any syringing of the puncti and canaliculi. A nasal endoscope confirms passage of the fluorescein into the nasal fossa. If there is any doubt, the ophthalmologist could be requested to carry out the assessment and syringing.

26. Falling success rate with passage of time

It is well to remember that some cases do not maintain the initial improvement on long-term basis, and it is advisable to follow these patients by postal survey to understand the natural course of the condition after surgical intervention.

Sadiq (1997) and Maini (2007) reported that the initial high success rate with laser surgery was not maintained through passage of time. Sixty patients underwent laser procedures and 66 had cold-surgery instrumentation. At three months, the success rate was 82% for the laser group and 76% for cold instrumentation. At twelve months, the figures were 68% and 74% respectively. The most likely cause was thought to be fibroblastic reaction induced by the laser.

27. Outcome criteria

So far, subjective scoring alone has been used to measure outcome. In unilateral cases, it is common for the patient to compare the results of the operation with the 'good' eye. In bilateral cases, the patient compares improvement with the severity of watering prior to the operation. In the immediate postoperative period, particularly when no stent has been inserted, improvement is both immediate and dramatic, lasting for up to a week. As the healing proceeds, the symptoms may return, but they are both less severe and less frequent. When the improvement is partial, it is usual for the patient to complain of eyes watering in cold winds, or in the smoky atmosphere of pubs and restaurants. In failed cases, the improvement may be very short-lived – only a day or two. The symptoms then recur, showing no improvement whatsoever. Even though the selection of cases and the surgical steps are comparable in every respect, it is not possible to achieve 100% results. It is likely that some of these cases have some other causes for failure, such as atony of the lacrimal pump. The success rate may improve as more experience is obtained in centres actively involved in laser DCR. Currently, a medium to long-term success rate of between 70 and 80% has been reported for ENL-DCR, and of as high as 80-95% for cold-instrument EN-DCR. However, for TC-DCR, this figure varies between 57 and 80%, which is lower than that obtained with the cold-instrument endonasal or external approaches. The patient's individual perception of symptoms has great bearing on whether success is considered to have been achieved or not.

28. Management of laser DCR failures

In cases that fail to improve after endonasal laser DCR, an accurate assessment of the pathology is carried out. The nose is examined for any synechiae or high DNS. The ophthalmic surgeon undertakes further flushing. He will also assess whether there are causes other than obstruction of the duct. The integrity of the whole of the lacrimal system needs to be assessed, in case there is any other cause of failure. In some cases, probing of the lacrimal pathway and imaging (digital dacryocystography) is also performed.

If no further obvious cause for the failure can be found, then one further attempt at endonasal DCR seems logical. In cases in which even the second endonasal attempt fails, an external approach may be the final arbitrator!

29. Cost effectiveness of ENL-DCR

The capital outlay for the laser equipment is high. Diode and KTP fibres are marketed for single use, thus adding to the overall cost of the procedure. The Ho:YAG laser optical fibre has a multiple use specification, and its use per patient is less expensive. It may be that laser DCR is suitable for larger centres, which can pool patients from surrounding districts. The capital costs per procedure can thus be reduced. However, such a possibility only exists where socialised medicine is practised, as in the UK!

30. Laser DCR as revision surgery for failed EX-DCR

EX-DCR may be unsuccessful for several reasons, but is predominantly due to excessive scarring. It is likely that endonasal DCR will help such cases, but the outcome cannot be predicted on account of the excessive scarring that may involve the canaliculi and common duct. When excessive scarring of the stoma is the main reason for failure, effective revision surgery can be performed with the laser, which can remove the scarred tissue bloodlessly. It is important that the power setting is high enough to effect vaporisation rather than charring since the latter will be a further source of excessive scarring. Stenting of revision cases is perhaps more logical than scientific (Woo *et al.*, 1998).

31. An alternative to DCR

Schaudig and Maas (2000) used the polyurethane nasolacrimal duct stent as an alternative to conventional techniques for the treatment of lower tear duct obstruction, in order to evaluate the clinical success rate after a follow up of two years. Nasolacrimal duct stent implantation was attempted in 19 patients with nasolacrimal duct obstruction proven by digital subtraction dacryocystography. The median age of the patients was 50 years, and the minimum duration of symptoms was three months. Patients were followed up at one week, six months, and one and two years after the procedure. Eighteen stents were implanted in 17 patients without surgical complications. All stents proved to be patent at the end of the procedure. Success rate, defined as the proportion of patients free of symptoms, was 66.6%, 55.5%, and 50%, after one week, six months, and one year, respectively, and remained unchanged thereafter. Three stents had to be removed at between six months and two years after implantation. Histological examination showed granulation tissue growing into the opening and obstructing the stent in one case. They state that implantation of a polyurethane nasolacrimal duct stent is an alternative to conventional techniques in lower tear duct obstruction. Its overall success rate is lower than that reported after conventional DCR, but the procedure is fast, safe, and reversible.

However, Lee *et al.* (2000) reported a much higher success rate in 59 procedures in 53 patients in a retrospective noncomparative study of the polyurethane (Song) stent in the treatment of nasolacrimal duct obstruction. No fluoroscopic guidance was used, even for the critical area of the junction between the lacrimal sac and the nasolacrimal duct or for the nasolacrimal duct. A polyurethane nasolacrimal stent was placed by introducing a guidewire through the superior or inferior punctum into the canaliculus and advancing it across the obstruction into the opening of the inferior meatus of the nasal cavity. The mean follow-up period was 22 months (range, 12-48 months). Complete resolution of epiphora was accomplished in 55 (93.2%) of the 59 eyes. There was recurrence of epiphora in four cases due to obstruction of the stent in three cases and obstruction of the common canaliculus by recurrent dacryocystitis in one. Lee *et al.* conclude that polyurethane stenting without fluoroscopic guidance seemed to be a valuable alternative for the primary management of nasolacrimal duct obstruction before DCR.

32. Conclusion

The endonasal technique is elegant, simple, quicker, and less invasive than the more traditional external approach. It can be performed either under general or local anaesthetic, with or without neuroleptoanaesthesia. There is no facial skin incision and therefore no facial scar. The pump mechanism is left undisturbed.

The normal physiology of the lacrimal system is preserved. There is no dissection of the medial ligaments and muscles. The precise location of the nasolacrimal duct and sac in the lateral wall of the nose can be determined by transillumination. Postoperative morbidity is relatively low. No major complications were noted in the authors' series. All minor complications were temporary and were resolved without any long-term sequelae. Hospital stay is short. The almost non-existent risk of postoperative bleeding means that most patients can be discharged on the same day, or the day following it. The complication rate is comparable or lower than the external approach. However, there is an indisputable learning curve. The advantages of laser DCR have to be weighed up against the relatively better results of EX-DCR or endonasal DCR using conventional instruments. Whether the use of topical antimetabolites can reduce the differences in success rates still has to be confirmed. Nevertheless, as a procedure that is truly minimally invasive, endonasal laser DCR plays a useful role in the management of lacrimal disorders.

Although the surgical procedure appears to be 'simple', the surgical outcome is anything but. Despite a number of modifications, including the application of antimetabolites to the site of the fistula, the surgical outcome is not yet equable with external or endonasal cold-instrument DCR (VO and NJ). It is likely that a combination of laser and cold instrumentation to remove the unwanted laser effects (charring, thermal damage zone) is probably required, and in one author's (VO) institution work is progressing in this direction. It is likely that, in the future, surgical laser measures will not stop at just the management of post-saccal stenosis, but will also include stenosis anywhere in the lacrimal pathway. Based on his own work, one author (VO) believes that a watering eye service should be jointly set up between the ophthalmic and the ENT department. This would enable the standardisation of protocol, global management of watering eyes, and meaningful audit of the surgical outcome in order to improve results.

Laser can be used in different ways to perform a DCR. The endonasal approach was until recently the best approach providing good success rate with minimal side effects. The rhinostomy can be performed with the laser only but better results have been obtained when it is combined with a drill or a bone resection in order to have a wide rhinostomy. The haemostatic property of laser enhances the view and adds to precision. It also shortens the operation time.

The transcanalicular approach with creation of a bony window is, from a theoretical point of view, a very elegant technique. But once more the definitive size of the stoma and the thermal damages caused by the absorption of the laser energy into the tissue explain less impressive results compared to the endonasal approach. Intubation is also mandatory for at least three months postoperatively.

The dacryoscope allows a direct vision on the contents of the lacrimal pathway. With the development of this technique, the surgeon can do a more precise assessment of the lacrimal system and can choose which procedure to do according to the information provided by this examination (dacryocystorhinostomy or endoluminal recannalisation). Laser dacryoplasty is certainly a very promising procedure, particularly for canalicular stenosis and revision surgery.

Finally, whatever the type of surgery performed, we must keep in mind that laser generates thermal damage to the adjacent tissue and a fibroblastic reaction which promotes development of granulation and late closure of the rhinostomy. As a consequence of this, the surgical rhinostomy must be wide. Combined approaches (endocanalicular and endonasal approaches) are therefore highly recommended to get the optimal success rate.

The era of endoscopic and minimally invasive surgery has given the profession an imaginative and innovative opportunity to fine-tune the old surgical methods, which by today's standards seem so gross. In the broader picture of the vast technological advances for more serious and demanding conditions, the humble watering eye seems to present a challenge to achieve a 100% success rate! Even in this second edition (2013) we have to state that the last word has not yet been said on this subject!

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MCQ – 21. Laser-assisted dacryocystorhinostomy

1. Dacryocystorhinostomy (DCR) is indicated in
    a. Epiphora due to ectropion,
    b. Epiphora due to stenosed canaliculi
    c. Obstruction in lachrymal sac
    d. Obstruction in lachrymal duct
    e. Obstruction in lachrymal sac and lachrymal duct

2. Plica lacrimalis
    a. Is a fold of mucosa separating lachrymal sac from the lachrymal duct
    b. Damage to plica ventricularis leads to epiphora
    c. Is synonymous with the valve of Hasner or the valve of Cruveilhier.
    d. Is not present in every patient
    e. Is not important in the management of epiphora

3. Probing the lacrimal pathway with a smooth double-ended Bowman's probe may
    a. End in a 'soft stop' confirming obstruction in the sac
    b. End in a 'hard stop' confirming obstruction in the sac
    c. End in a 'soft stop' confirming obstruction in the canaliculus
    d. End in a 'soft stop' confirming thickened mucosa in the lachrymal duct
    e. End in a 'soft stop' confirming obstruction in the common duct

4. The external approach to DCR
    a. Gives a very high success rate and is thus considered gold standard against which all other methods are judged
    b. Due to a dependable high success rate, external DCR should be considered as the first line of management
    c. The downside of the external approach is its unsuitability in elderly population
    d. The downside of the external approach is high morbidity compared to the endonasal or Transcanalicular approach
    e. The downside of the external approach is facial scar

5. The endonasal approach is preferred as the first line of management by most surgeons because
    a. Its judicious management can result in a high success rate
    b. It is associated with a low morbidity with no facial scar
    c. Any associated nasal pathology can also be dealt with simultaneously
    d. In failed cases, it can be repeated
    e. All of the above

6. Although solid bone covers the whole length of the sac, the bone is thin at
    a. The inferior aspect of the uncinate process in the middle meatus
    b. Just anterior to the dense frontal process of the maxilla.
    c. The posteromedial aspect of the lower sac and upper duct
    d. Just antero-inferior to the dense frontal process of the maxilla
    e. The insertion of the bony middle meatus

7. Removal of bone lachrymal canal with the laser
    a. Is quick if it is used at high powers
    b. Is tedious
    c. Is associated with much thermal damage
    d. Is contributor to restenosis
    e. Is quick and efficient irrespective of some of its disadvantages

8. Microdrill is a preferred method of removal of the bone because
    a. It is quick
    b. It is not associated with thermal damage
    c. It is not associated with plume formation
    d. It does not cause damage to the membranous lachrymal sac
    e. All of the above

9. The main disadvantage of the trans-canalicular approach is
    a. Damage to the delicate mucosa of the lachrymal system
    b. The tendency for the fibre to go posteriorly in the direction of the orbit due to anatomical configuration of the lachrymal canal
    c. A potential damage to the orbital contents due to entry of the fibre in to the orbit.
    d. A more posterior position and a smaller diameter of the rhinostome
    e. All of the above

10. Stent in the stoma
    a. Minimises incidence of stenosis
    b. Can cause granulations and thus promotes stenosis
    c. Must be kept in situ for at least six months to optimise benefit
    d. May result in its migration and cut through the canaliculi
    e. Is time consuming

Chapter 22

Nasal turbinate surgery

V. Oswal, J. Krespi and A. Kacker

1. Introduction

Surgery for enlarged turbinates is routinely undertaken to relieve obstruction to nasal breathing. Two fundamentally different procedures are practised, *viz.*, mechanical and thermal. Broadly, mechanical removal is achieved by cutting away excess tissue with a cold instrument such as turbinectomy scissors. The thermal coagulation is undertaken with red-hot cautery, submucous diathermy, cryoreduction, and the use of radiofrequency.

Cold instrument surgery involves the instant and gross removal of the obstructing tissue. In contrast, the thermal method produces irreversible damage at the *cellular* level by coagulation. The slough consisting of necrosed and coagulated tissue is removed by the body defence mechanism, by inducing an inflammatory response. Thus, the thermal method leads to delayed tissue loss. The inflammatory response and the subsequent scarring are proportional to the thermal damage, which depends on several factors discussed below.

Lasers are thermal instruments, heating and destroying the soft tissue due to their photothermal property. However, compared to submucosal diathermy (SMD), there are significant differences. When applied on the surface in sufficient intensity, the laser will vaporise the tissue and ablate it instantly. There is also a spread of energy in the deeper tissue, but the extent of this spread is largely dependent upon the wavelength used and the user-controlled laser parameters. The inflammatory response can be minimised, adding to patient comfort in the postoperative period. Intraoperative haemostasis is almost total, and therefore, the procedure remains completely under visual control. Vaporisation can be targeted to the hyperplastic areas only, thus sparing the intervening mucosa.

2. Nasal obstruction

Normally, the sense of breathing is under the control of a number of physiological factors. These consist of nasal cycle, nasal resistance, mucus production and its contents, nasopulmonary reflex, and nasal flow patterns. Any exaggeration of these factors can result in the symptom of obstruction to nasal breathing. In such cases, the obstruction is short-lived and it may be recurrent rather than chronic.

The symptom of persistent nasal obstruction can result from a variety of factors:

2.1. Deformed anatomical structure

The most common deformed anatomical structure is the nasal septum. A concha bullosa may be large and, rarely, there may be a unilateral or bilateral choanal atresia.

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2.2. Pathological process

Pathological processes affecting the mucosa lead to various gross and microscopic changes, which cause nasal obstruction. The commonest cause is polypi, or an enlarged turbinate.

2.3. Multifactorial cause

Although it is convenient to divide the causes of nasal obstruction as above, frequently the aetiology is multifactorial. The effects are then additive and only a careful history and endoscopic examination, supported by appropriate investigations, can identify the various causes and the contribution they make to the symptom of nasal obstruction.

This chapter deals with the nasal obstruction caused by hypertrophy of the turbinate. The inferior turbinate is most frequently involved, but occasionally, the middle turbinate is also implicated. The varied aetiology of hypertrophy of the turbinates is abbreviated here for want of space, and the reader is advised to study the numerous titles available on this topic.

3. The turbinates

The inferior turbinate is situated on the lateral wall of the nose. It consists of a bony turbinate covered with the respiratory mucosa of the nose. It is a three-dimensional structure with a superior, medial, and inferior surface. It extends from just beyond the nasal valve, where it forms the 'head', to the posterior choana, where it usually ends in a 'tail'.

Anatomically, the bony thickness of the inferior turbinate is greatest in the anterior third (Brain, 1987). However, the main body of the soft tissue covering the turbinate is usually thickest in its middle third. Posteriorly, in the majority of cases, the turbinate diverges from the septum, and only a few cases present with the classical mulberry type of hypertrophy obstructing the choana.

The pathological process usually affects the inferior turbinate, and the following description is thus limited to the inferior turbinate ('the turbinate'). The turbinate is covered by respiratory mucosa, which is the working tissue of the nose. The mucosa and submucosa are by far the largest and the most dynamic structures, responding to the various stimuli. Its thickness can vary enormously in response to endogenous and exogenous stimuli and to pathological processes. A rapid response to a stimulus is possible because of the rich blood supply and loose submucosa. The total blood flow per cubic centimetre of turbinate mucosa is greater than in the muscle, brain, and liver (Drettner and Aust, 1974). The blood vessels are continually under the control of the opposing action of the sympathetic and parasympathetic nerve supply. In addition, non-adrenergic and non-cholinergic (NANC) receptors are also important factors in the development of vasomotor rhinopathy, refractory to usual medication (Mladina and Heinzel, 1995).

4. Hypertrophy of the inferior turbinate

The narrowest part of the nasal airway is in the valve area. It is formed by the septum, upper lateral cartilage, pyriform aperture, and the anterior edge of the inferior turbinate. Some parts of the vestibule mucosa have erectile characteristics. The head of the turbinate can sometimes swell up by as much as 5 mm (Haight and Cole, 1983). Kensei *et al.* (1989) showed that hypertrophy of the anterior part of the inferior turbinate can cause a disproportionately greater increase in airway resistance.

A detailed description of the various aetiology and pathogenesis causing hypertrophy of the turbinate is outside the scope this book. Briefly, baseline differentiation is made between allergic and non-allergic rhinitis. However, this distinction is suitable for medical management. Surgical management is not specific to any particular aetiological factor.

4.1. Allergic hypertrophy

In allergic rhinitis, the mucosa and submucosa are engorged with oedema. The nasal obstruction caused by allergic hypertrophy of the inferior turbinate may be seasonal or perennial. Rhinorrhoea, sneezing, and itching of the eyes are also prominent features, particularly in seasonal allergic rhinitis. The mucosa is typically pale, boggy, and easily compressible. The enlargement is usually bilateral and uniform, involving the medial surface of the entire length of the inferior turbinate. In addition, the inferior surface may also be enlarged along the floor of the nose.

4.2. Non-allergic hypertrophy

The non-allergic causes of turbinate hypertrophy include such conditions as vasomotor rhinitis, rhinitis medicamentosa, and compensatory hypertrophy contralateral to the deviated nasal septum. The nasal obstruction may be unilateral, bilateral, or may vary from side to side. It may be influenced by a variety of factors. The response to topical decongestants is temporary, and prolonged use may lead to rhinitis medicamentosa with purplish dusky discolouration of the mucosa. In some cases, the mucosa may be more reddish, vascular, and chronically thickened. Enlargement of the turbinate may be restricted to the site of the valve, or may extend posteriorly to a variable distance. The so-called compensatory hypertrophy of the turbinate is usually on the contralateral side of the convexity of the deviated nasal septum and may be limited to the concave portion of the deviation. The posterior end alone may be hypertrophied in some cases; this condition is called mulberry hypertrophy on account of its resemblance to a mulberry.

It is not uncommon to find a considerable variation in turbinate hypertrophy in patients with similar aetiologies. Numerous conditions influence the state of the turbinate, which responds to such factors as environment, emotions, hormonal influences, etc. A well-planned clinical evaluation enables the surgical reduction to be optimised, with a satisfactory outcome and low morbidity.

When the enlargement of the turbinate is associated with anatomical deformities, such as deviated nasal septum, alar collapse, hypertrophied concha bullosa, etc., an accurate assessment of the contribution of each condition to the nasal obstruction is essential. The priority for one particular procedure over another can then be advised, and the second procedure, if required, can be staged. Occasionally, both procedures can be undertaken simultaneously.

Apart from hypertrophied turbinates, patients suffering from atrophic rhinitis also complain of nasal obstruction. This may have a dual origin: loss of the sensation of breathing, and the presence of crusts. Nasal obstruction due to atrophic rhinitis, as well as that caused by acute rhinosinusitis, is inappropriate for surgery and is excluded from any further consideration.

5. Surgical management of hypertrophy of the turbinate

When the obstruction is caused by a hypertrophied turbinate alone, it is usual to exhaust the various medical treatment options before embarking upon surgical reduction. Acoustic or anterior rhinometry is not useful for patient selection (Roth and Kennedy, 1995).

It is useful to review the salient features of non-laser methods for turbinate surgery, so that the role of the laser can be assessed and validated.

6. Cold instrument reduction of the turbinate mass

6.1. Lateral out fracture

This consists of pushing the whole of the inferior turbinate laterally so that it lies closer to the medial wall of the maxilla. When pushed so far laterally that it lies in the antrum, the procedure is termed antroturbinopexy. Such procedures have little to recommend them, since the turbinate often resumes its original position.

6.2. Submucous resection of turbinate

This procedure is mainly applicable for the reduction of the bony inferior turbinate. It is carried out by lifting the mucosa off the bony turbinate and nibbling it in order to reduce its size. The flap is then replaced. Submucous resection is difficult to carry out in narrow, pinched up nostrils, and is usually confined to anterior resections.

6.3. Turbinectomy

Turbinectomy with scissors is variously described as partial turbinectomy or trimming of the turbinate. Adequately undertaken, it effectively reduces the bulk of the obstructing soft tissue in a minimum of operating time.

6.4. Radical turbinectomy

Radical turbinectomy removes both bony and soft tissue almost flush with its attachment to the maxilla. Over-correction of the nasal airway can lead to atrophic rhinitis with crusts, and to even more perception of the obstruction due to a lack of the sensation of breathing. Moore *et al.* (1985) reviewed 18 patients two to five years after total turbinectomy. Although 80% of the patients had a patent airway, 89% complained of nasal crusting and 66% had symptoms of atrophic rhinitis. Radical total turbinectomy has no place in the management of hypertrophy of the turbinate, and should never be undertaken.

7. Disadvantages of cold instrument surgery

Although reduction of the bulk of the enlarged turbinate can be achieved very quickly with turbinectomy scissors, there is a trade off.

7.1. Intra- and postoperative bleeding

One considerable disadvantage of the cold-instrument method is intraoperative bleeding. The initial cut results in immediate flooding of the nasal fossa with copious bleeding, and any further reduction is carried out more or less by feel rather than under direct vision. The bleeding can be reduced somewhat by initial decongestion of the mucosa. Nevertheless, the procedure is quite bloody, requiring insertion of a nasal pack in order to achieve postoperative haemostasis by pressure. It is necessary to leave the pack *in situ* for a few hours.

In some cases, the bleeding may continue from the front of the nose around the pack, or into the postnasal space. Therefore, the pack needs to be replaced, usually under a further general anaesthetic (GA). A postnasal pack is also inserted to support the anterior pack. Occasionally, it is necessary to re-pack the nose even a third or fourth time before the bleeding can be brought under control. Some 8% of turbinectomy patients have postoperative haemorrhage and, in 1%, it is severe.

7.2. Inflammatory response

Cold instrument turbinate reduction leaves a raw surface, which results in gross postoperative inflammatory oedema.

7.3. Postoperative packing

The nasal packing adds further to the operative trauma and increases the inflammatory response. The pack for postoperative haemostasis has some undesirable effects: It is very uncomfortable; its far end may slip into the patient's postnasal space and oropharynx, causing a choking sensation; its removal is a traumatic experience for the patient; in a small number of cases, further packing is necessary. In some centres, a trend has emerged not to pack the nose in order to minimise patient discomfort.

Therefore, it is not surprising that alternative methods to reduce the bulk have made inroads.

8. Conventional thermal reduction

Thermal reduction has the advantage of intraoperative haemostasis. Several methods have been used:

8.1. Red-hot cautery

An electrically heated, red-hot loop causes destruction of the mucosa and provides concurrent haemostasis, due to shrivelling of the tissues. It can be performed as an outpatient procedure, under local anaesthesia. The method fell into disrepute due to the bulky carrier handle of the loop, which could not be passed into the posterior part of the nose. The spread of energy within the tissue is random. The extensive thermal damage results in a severe inflammatory reaction with much crusting. Some 20-30% patients develop synechiae and crusting (Brain, 1987).

8.2. Submucosal diathermy

The procedure of submucosal diathermy (SMD) involves inserting a diathermy needle into the submucosa and advancing it as far as possible. The diathermy is then activated and the needle is slowly withdrawn. The thermal energy results in coagulation and shrinkage of the submucosal tissue.

It is not possible to control the amount of energy deposited in the tissue and much depends on the surgeon's own judgement. The mucosa suffers varying thermal damage, sometimes to the extent that it blanches. The end point is arbitrary, and some operators consider blanching of the mucosa to be the end point of the procedure.

There is an intense inflammatory response and crusting in the postoperative period. The coagulated tissue is gradually removed and replaced by fibrous tissue, thus reducing the size of the enlarged turbinate. The reduction may be adequate, or the turbinate can be under- or over-reduced. The surgical outcome is not always predictable, and it is not unusual to see uneven shrinkage of the turbinate. The spread of energy to the periosteum may devitalise it and result in avascular necrosis of the bony turbinate (Brain, 1987). Clear crusting indicates that the mucosa was devitalised due to the conduction of energy submucosally, and this defeats any claims that the procedure spares the delicate mucosa.

The obstruction is worse initially, due to a marked inflammatory reaction. Haemorrhage and adhesions are possible risks.

Despite these considerations, SMD remains a widely practised method of reduction of turbinates, on account of its relatively bloodless nature. The patient can be discharged home on the same day, or the procedure can be performed as an outpatient.

8.3. Cryosurgery

Cooling of tissue causes cellular necrosis, which is removed by an extensive inflammatory response. As with SMD, the energy levels cannot be controlled accurately. In some cases, separation of the crust can produce significant postoperative haemorrhage. The long-term results are doubtful.

8.4. Radiofrequency reduction

Radiofrequency has been used in a number of otolaryngological procedures. The heat generation is not from the electrodes, as in conventional cautery, but from the resistance generated in the tissue around the electrode tip (Organ, 1976). High-frequency coagulating current is applied with a ball-tip electrode, resulting in thermal damage, which produces an inflammatory response, with healing, by the scar tissue. This technique offers a number of advantages: the capital outlay is relatively small; the electrodes are reusable; the waveform can be varied to produce a combination of ablation and coagulation; there is far less postoperative morbidity due to the relatively pain-free recovery.

9. Laser surgery of enlarged turbinates

Unlike conventional methods, which consist of gross turbinate reduction, the laser can be used to reduce specific, obstructing areas of the turbinate with considerable precision. An optical fibre measuring only 600 mm can deliver ablation energy to a spot no greater than 0.5 mm in diameter. It is possible to vaporise tissue measuring as little as 2 or 3 mm^3 situated anywhere along the length and breadth of the turbinate, without damaging the surrounding normal structures.

10. Assessment of nasal pathology

The feasibility of such precision surgery calls for accurate preoperative assessment of the pathology, so that the ablation can be selectively targeted in order to minimise trauma and to preserve function. Conventional examination with a Thudicum speculum allows a view of the anterior third of the nasal fossa only, and by itself, is inadequate. Nasoendoscopy to identify and localise the target tissue for ablation is invaluable, and should be an integral part of any endonasal assessment for laser surgical procedures.

10.1. Nasoendoscopy

Nasoendoscopy gives valuable information of the entire nasal fossa. It also provides photographic and video archiving for comparison with the operative results. It is usually possible to undertake nasoendoscopy without topical anaesthesia and decongestants. Such an examination allows the obstruction to be seen in its 'virgin' state, and surgery can optimally be directed towards the obstructing part of the turbinate only. Nasoendoscopy will also identify any additional pathology, such as an anterior spur, high deviation of the septum, presence of a posterior spur, state of the choana and the postnasal space, etc. The presence of any such concomitant pathology may result in continuation or recurrence of symptoms following apparently successful laser turbinate surgery.

10.2. Site of enlargement

The hypertrophy usually affects the inferior turbinate, although, at times, the middle turbinate is also enlarged. The enlargement may affect the whole length of the turbinate, or may be limited to parts of it. Even relatively small hypertrophy at the valve may result in a disproportionate nasal obstruction due to a compromised inlet. Although the medial surface is the one most commonly affected, the hypertrophy may extend to, or be limited to, the inferior surface.

10.3. Type of enlargement

An enlargement due to allergy is usually oedematous and boggy, whereas other aetiology may produce a combination of oedema and cellular infiltrate. Sometimes, the enlargement is solid, as in cases of rhinitis medicamentosa, with no oedema. The type of enlargement can have a bearing on the effectiveness of the laser strikes for its ablation. An oedematous component will absorb greater energy from most laser strikes, resulting in efficient vaporisation. A solid cellular enlargement will result in less energy absorption and may result in greater thermal damage with greater inflammatory response.

10.4. Allergy testing

Generally, the long-term success rate of the surgical management of allergic hypertrophy of the turbinate is somewhat poor when compared with that of non-allergic causes. Reporting upon the results of 350 cases managed by laser, Selkin (1985) found that all 28 patients (8%) who had recurrences also had severe hypertrophic allergic rhinitis. However, all these patients reported greater effectiveness of anti-allergic medication following laser reduction. Thus, investigation for potential allergies can alert the surgeon to expect recurrence of the obstruction in some patients. These patients can then be offered concomitant or sequential medical management following reduction of the turbinate.

11. Instrumentation for laser surgery

The framework of the anterior part of the nose is mainly cartilaginous and yielding, whereas posteriorly, it becomes rigid due to the bony pyriform ridge. Self-illuminating Killian's speculae of various sizes can provide quick access to most areas. However, the rim of the ala remains vulnerable to accidental burns when using a free beam such as the CO_2. Selkin (1986) reported alar skin burn which was thought to be due to heat transmission from a speculum. It may seem inconceivable that strikes on tissue in the vicinity of the blade of the speculum can result in the conduction of heat proximally, causing alar burns. However, it is worth noting that metal is a good conductor of heat and thus all biological surfaces in contact with metal instruments are vulnerable to inadvertent burns. It is prudent to use short repetitive bursts of energy to vaporise the tissue layer by layer, in order to avoid potential heat transmission via a speculum. This method also allows frequent assessment of the surgical site. Alar burns can also occur if the ala is 'brushed' tangentially by a free CO_2 beam. Flying charred debris landing on the alar skin may be hot enough to cause burns. Whatever the source of burn, it is necessary to be vigilant.

Fibre delivery lasers offer protection to the alar skin. However, the cladding can get damaged and part of the energy may leak out. This can easily be recognised when the intensity of the energy in the spot drops below its anticipated level. The whole length of the fibre should be inspected. It may be necessary to cleave the fibre to freshen the tip.

12. Visualisation of the operation site

12.1. Endoscope

A zero-degree endoscope provides a good illuminated image of the target. However, it does not magnify the image, and thus it is a telescope rather than a magnifier. A beam splitter with the camera provides an imaging facility.

12.2. Operating microscope

The operating microscope offers several advantages for endonasal laser surgery. A 300-mm objective provides an adequate working distance. A beam splitter accepts the camera, and the optics magnify the target. Since the objective is some distance away from the operating site, it does not get soiled with debris, blood, or secretions. It is possible to use both the free-beam CO_2 as well as any fibre-transmissible laser. The depth of field is good and target strikes, coaxial. A self-retaining Killian's speculum frees both hands. The energy can be delivered with one hand, while the other is holding the suction cannula close to the operating site.

13. Fibre delivery systems

A fibre carrying a transmissible laser beam can be advanced alongside the endoscope so that the tip passes beyond the lens and can be seen through the endoscope. It is usually necessary to pass the fibre through a rigid metal channel in order to achieve stability of the tip. The fibre passing alongside the endoscope always remains around the rim of the endoscope, and cannot deliver the beam coaxially. It is necessary to direct the tip of the fibre laterally in order to achieve target strike. A further channel to remove smoke and debris is also necessary, so that an unobstructed view of the target is continuously available. Commercially constructed instruments, known as scrubbers, are available. They have three separate channels: one for the endoscope, another for the fibre, and the third for the suction. A device for steering the tip of the fibre is incorporated into the fibre channel. All three channels are held together in a sleeve which further incorporates a flushing device to keep the lens clear of debris and blood (Fig. 1). Although highly engineered, the instrument lacks the manoeuvrability and calls for a certain degree of dexterity.

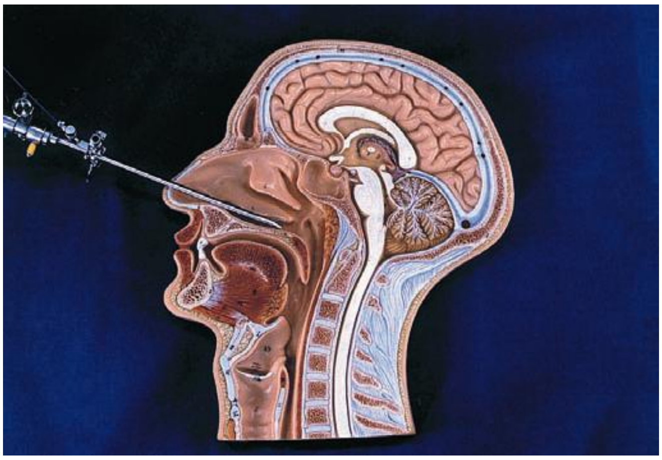


Fig. 1. Illustration shows the position of the laser fibre application sheath for laser surgery of turbinate hypertrophy.

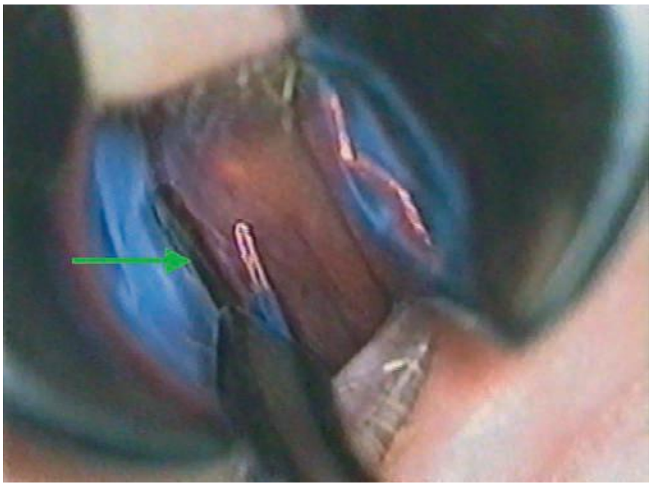


Fig. 2. The Oswal suction-fibre-cannula is a dedicated instrument specially designed for fibre delivery of the laser energy.The arrow shows a guide with a channel for suction.

The Oswal suction-fibre-cannula (Fig. 2) is a dedicated instrument specially designed for fibre delivery of laser energy. Although it incorporates three channels, the outer diameter is only 4.1 mm. The fibre channel and main suction channel end distally at the same level, while the third suction channel extends from the rim of the distal end for some 1.5 cm. This protrusion acts as a guard. It has an orifice that provides suction in the immediate vicinity of the operating site. The fibre is advanced so that the tip lies against the orifice in the guard. When the beam strikes the target, the smoke and debris are instantly removed by the suction in the guard. Any ambient debris and smoke are sucked away by the main suction channel. Thus, this 4.1-mm diameter Oswal suction fibre cannula provides an uninterrupted view of the target, and can be used for all fibre-delivery lasers and for endonasal laser surgery with a microscope as well as with an endoscope.

The CO_2 laser energy cannot be delivered in its free beam mode when being used in conjunction with the nasoendoscope, it is necessary to deliver the beam via a waveguide.

14. Dedicated instruments of other designs

It is necessary to protect the skin of the alar margin from tangential burns when the free beam of the CO_2 laser is being used. The skin is also vulnerable to hot flying debris from charred particles. An aural speculum with built-in suction provides good protection to the skin of the ala, but access is restricted to the anterior nasal area only.

15. Other instruments

Apart from general nasal instruments, ribbon gauze, decongestants, and diathermy are useful additions for controlling any excessive bleeding.

16. Lasers for turbinate surgery

Laser reduction of inferior turbinate involves ‘debulking’ or volume reduction of the hypertrophied mucosa. A variety of wavelengths are suitable to affect this. In the past, the use of a particular wavelength was determined mostly by what was available within the department rather that a definitive wavelength producing optimum results. Nowadays, a number of wavelengths may be accessible, in which case the surgeon should use the wavelength that works best in his or her hands to produce the desirable effect. However, at the same time, some consideration should be given to the peculiarity of each wavelength interaction with the target tissue, the hypertrophied mucosa of the inferior turbinate.

Currently, Ho:YAG, Diode, CO_2 and KTP lasers are used for turbinate surgery. Detail description of each wavelength and its interaction with the tissue has been covered in the section on basic laser science. Briefly, a laser which is absorbed efficiently on the surface will remove the tissue instantly with very little deeper thermal spread. The tissue is ablated layer by layer. Limited coagulation of the deeper tissue produces minimum postoperative oedema and minimum crusting. Ho:YAG laser and the CO_2 laser fall in to this category since they are maximally absorbed by the water in the mucosa. Diode and KTP lasers are not absorbed efficiently at the point of strike. Their energy spreads deeper in the tissue and thus postoperative inflammatory oedema and crusting is greater and lasts longer.

Widely available diode laser has been consistently used for turbinate surgery. Sroka *et al.* (2007) compared long term results following turbinate surgery with Ho:YAG laser and the diode laser. At three years, 67.5% of Ho:YAG treated patients maintained the improvement, whereas the score was higher for diode, at 74.4%. However, rhinomanometry revealed a significant improvement of the nasal airflow at both 6 months and 3 years after the laser treatment as compared to the preoperative data. Postoperative crusting lasted longer in the diode group when compared with the Ho:YAG group.

Thus, with subjective and objective evaluation, no significant long-term differences between Ho:YAG and the diode treated groups could be observed.

It is necessary to appreciate that the diode laser emits at a number of wavelengths, each with its own characteristic tissue interaction. When comparing the results, information on the wavelength of the diode is important. Havel *et al.* (2011) compared the two wavelengths of diode laser, emitting at 1,470nm and 940 nm, for volume reduction of hyperplastic inferior nasal turbinates by coagulation. One nasal cavity was treated using 1,470nm laser (4-5W power), the other one with 940nm laser (12W power), in noncontact mode. The mean operation time was significantly lower for 1,470nm as compared to the 940nm diode laser. Both sides showed a significant volume reduction on day 21 postoperatively regardless of the laser system used. They concluded that, given similar outcome, the 1470nm diode laser system took less operative time and therefore, cost effective.

Fibre delivery of the laser is an integral part of the usage of laser in turbinate surgery. Free beam CO_2 laser should never be used unless adequate precautions are taken to protect the skin of the ala and the cartilage underneath. Inadvertent burn results in nasal stenosis and cosmetic deformity.

Enlarged inferior turbinate generally shows only mucosal hypertrophy. *Bony* hypertrophy of inferior turbinate is uncommon. Lee and Kim (2010) used microdebrider in one group and the laser in the other group, to reduce hypertrophied inferior turbinate. Not surprisingly, they found that the microdebrider was more efficient in the reduction of the bony hypertrophy when compared to the laser, which was more efficient on the soft tissue hypertrophy.

17. Laser action on the turbinate tissue

With conventional surgical techniques, the procedure for ablating hypertrophied turbinates is fairly standard. Turbinectomy with scissors involves removal of varying amounts of hypertrophied tissue. The non-laser thermal methods of SMD and cryosurgery deliver an indeterminate amount of energy into the turbinate, causing thermal damage, without any correlation to eventual necrosis and loss of tissue.

The laser technology achieves restoration of the nasal airway by reducing the size of the turbinate in three stages:

- each laser strike results in instant loss of tissue by vaporisation. Thus, unlike SMD, as vaporisation continues, there is progressive opening of the nasal airway;
- at the conclusion of the operation, a layer of coagulated tissue covers the operation site. The extent of this zone depends upon the wavelength used. Ho:YAG and CO_2 wavelengths produce the coagulation zone by their thermal action. On the other hand, KTP, argon and diode lasers produce this zone due to the thermal action, as well as the high absorption of energy, by blood vessels in the bed of the operation site. Therefore, the zone of thermal damage is somewhat deeper with these lasers, and the fibrosis, more extensive. During the course of the next two to three weeks, the mucosal growth separates the slough, and crusts, thus improving the airway further;
- finally, repair by fibrosis contracts the wound and thus reduces the turbinate to its eventual size.

18. Influence of laser parameters on turbinate tissue

The extent of the reduction of the turbinate depends on the wavelength used, but it can also be varied by user-controlled parameters of the laser beam, and by the fluence (total amount of energy deposited at any particular point).

18.1. The wavelength

The turbinate mucosa is water-rich. The water content is even greater in oedematous, boggy, allergic turbinates. Generally therefore, wavelengths such as the CO_2 and the Ho:YAG, which has a high water absorption coefficient, are more suitable for vaporisation (Fig. 3). The greater part of the energy will be absorbed at the surface following a strike. Temperature levels of 100ºC are rapidly reached in successive layers as the strikes continue, and the tissue is continuously vaporised, layer by layer,

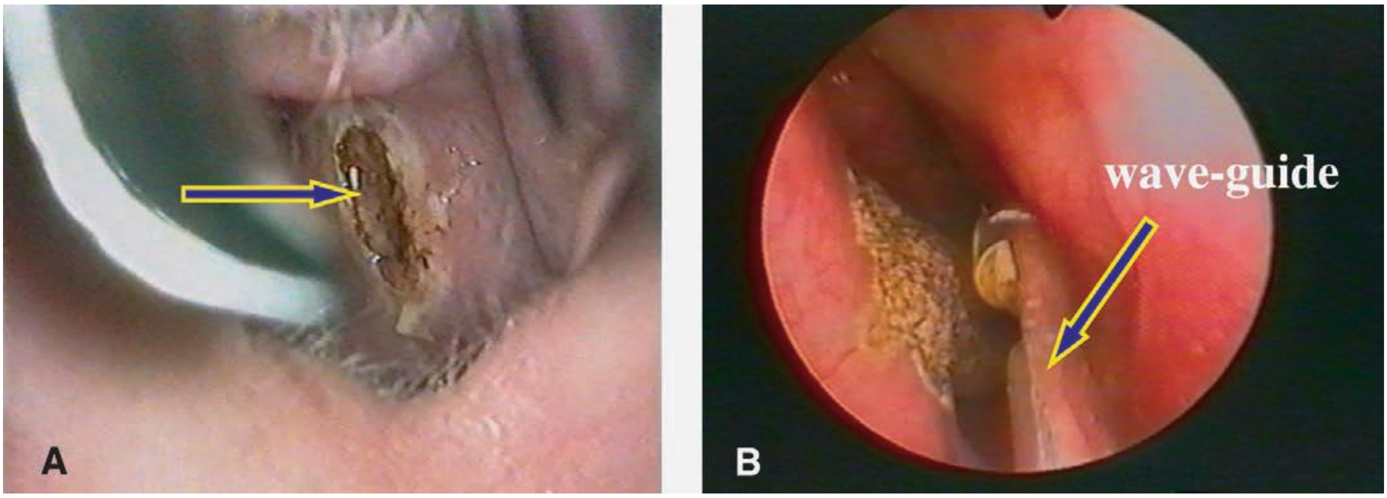
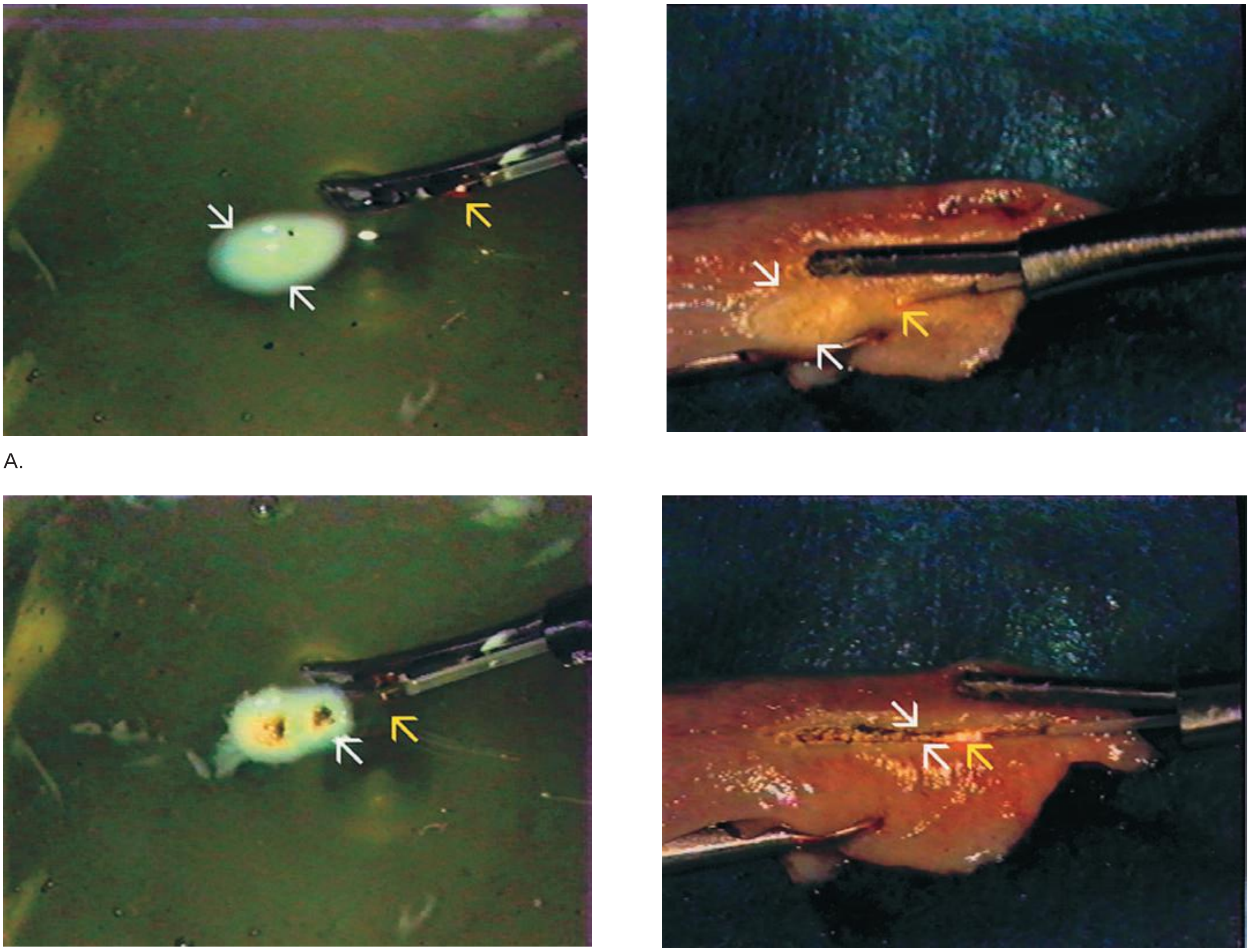


Fig. 3. Ho:YAG laser strike results in much deeper vaporisation (A) due to its high energy content. The vaporisation with the CO_2 is much shallower (B) and restricted to surface mucosal destruction.


A.

B.

Fig. 4 A, B. The laser effect can be varied between coagulation and vaporisation by simply varying the distance between the target and the fibre tip. The further away the tip, the more coagulation. In case of any bleeding, haemostasis can thus be easily achieved by withdrawing the fibre away from the target.

until the strike is discontinued. At this point, since most of the energy has been absorbed and spent in vaporisation, the tissue temperature drops rapidly. The thermal damage zone, immediately deep to the zone of vaporisation, is very shallow for the CO_2 and Ho:YAG lasers. Since it is the thermal damage zone that will be replaced by scar tissue, CO_2 and Ho:YAG laser strikes will result in a relatively shallow layer of scarring. The reverse is true of wavelengths with poor water absorption, such as the KTP, argon, and diode lasers.

18.2. Energy levels

With all lasers, as the level of energy increases, the speed of vaporisation increases. The thermal damage also goes relatively deeper as the tissue temperature of the surrounding tissue continues to rise, leading to a wider and deeper damage.

18.3. Fluence

Rapid movement of the laser spot on the tissue surface results in relatively superficial thermal damage.

18.4. Haemostasis

Intraoperative haemostasis is dependent upon the extent of thermal damage. Therefore, the CO_2 laser is a poor haemostat. The Ho:YAG laser causes shrinkage of the surrounding tissues due to high energy levels and high absorption by water. The KTP, argon, and diode lasers are also good haemostats as their absorption by water is relatively low, resulting in greater depth and width of the thermal damage zone. Furthermore, they are efficiently absorbed by pigmented haemoglobin in the blood, resulting in increased thermal damage where the turbinate is particularly vascular. However, the haemostatic effect of these wavelengths on the turbinate tissue is lost in the presence of active bleeding, since the blood absorbs most of the energy.

18.5. Fibre transmission

The ability to deliver the energy down a fibre of no more than 600 µm in diameter into the narrow confines of the nasal fossa offers a considerable advantage. Even if the anterior part of the nasal airway is partially obstructed, due to a deviated nasal septum, the energy can be delivered past the obstruction by manoeuvring the thin fibre towards the turbinate. The laser effect can be varied between coagulation and vaporisation by simply changing the distance between the target and the fibre tip. The further away the tip, the more the coagulation. Thus, if there is any bleeding, haemostasis can easily be achieved by withdrawing the fibre from the target (Fig. 4A,B).

The CO_2 laser is not fibre-transmissible. Hollow waveguides are available for transmitting the beam and reflecting it onto the target, but these tend to be bulky (Fig. 3B). There is also a significant loss of energy during transmission. Newly developed hollow waveguides are said to overcome these shortcomings. For further reading, see Chapter 59.

19. Choice of the ideal laser

The ideal laser should have the advantage of instantaneous bulk removal similar to turbinectomy with minimum inflammatory response, and at the same time, produce adequate thermal damage zone for intraoperative haemostasis. By limiting the depth of the thermal damage, the glandular component may be preserved, thus pre-empting any potential for dry nose with crusting. On the other hand, if rhinorrhoea is a troublesome symptom along with the nasal obstruction, then greater thermal damage to lessen the glandular element may be appropriate.

In practice, such refinements in the management of an obstructing turbinate are difficult to achieve. Not many departments will have the choice of several wavelengths to suit an individual case. Changing the laser during a surgical session is inconvenient and time-consuming. Also, most workers have used a wavelength which was ‘available’ to them in the department, with good clinical results and an acceptable level of risk and failure rates.

20. Surgical technique

This section describes general considerations, some of which are peculiar to laser usage. The actual laser application to the turbinates is described under 25.

21. Decongestants

It is universal practice to decongest the nasal fossa prior to turbinate surgery. The shrinking of the mucosa reduces intraoperative bleeding and increases the working space for instruments in the obstructed nose. However, it is difficult to assess accurately how much of the shrunk turbinate is to be removed, as it is no longer seen as an obstruction. Turbinate surgery with laser technology results in very little intraoperative bleeding, particularly in an allergic nose. Thus, it is not necessary to decongest routinely. The swollen turbinate can then be seen in its true virgin state and adequate reduction can be undertaken. If intraoperative bleeding becomes troublesome, ribbon gauze impregnated with decongestant and left *in situ* for a couple of minutes will always result in good intraoperative haemostasis, so that the procedure can be completed.

22. General or local anaesthesia

The choice of general or local anaesthetic is governed by a variety of factors, such as patient expectations, surgeon preference, availability of facility, etc., and no generalisation can be made. However, the laser surgical procedure is far less traumatic and, by itself, does not require an overnight stay.

22.1. Turbinate surgery under unsedated topical anaesthesia

Due to costs and other considerations, office based turbinate surgery is making inroads. The procedure is painless provided adequate anaesthesia of the sensitive nasal mucosa is achieved.

However, administration of topical anaesthesia is not a pleasant experience, and the patient should be warned to anticipate initial discomfort. An assurance should also be given that the discomfort is short-lived and once the anaesthetic takes effect, the procedure is painless. There may still be some discomfort from instrumentation and many patients fail to differentiate it from pain.

As in all local anaesthetic procedures, a high level of monitoring is necessary.

A smell of burning flesh also can be an unpleasant experience for some, and may indicate to them that something has gone wrong. Again, pre-warning will pre-empt this issue.

Under topical anaesthesia, the turbinates shrink. Allowance should be made for this so that removal of tissue is adequate and not less.

It is also customary to use decongestants under general anaesthesia to minimise intra-operative blood loss. One author (VO) used Ho:YAG laser under general anaesthesia. Ho:YAG laser is an excellent haemostat and preoperative decongestant to minimise intraoperative bleeding is unnecessary. This method allowed appreciation of the true extent of hypertrophy in its virgin state and therefore optimum reduction was possible to restore the airway, with due allowance for delayed tissue loss from lateral and deeper coagulation.

23. Day case, ambulatory or inpatient

Laser turbinate surgery does not require a planned overnight stay. The procedure can be undertaken on ambulatory patients with virtually no incidence of postoperative risks.

24. Protection of alar skin

The skin of the ala is vulnerable to accidental burn. Selkin (1986) considers that the alar rim cannot easily be draped with towels or gauze, and part of it remains exposed when using routine instruments. Aqueous-based gels are messy and can run onto the operating site, making laser strikes ineffective. An aural speculum with a length of suction cannula soldered to the inside of the wall can protect most of the alar skin.

25. Concomitant septal surgery

This is best avoided, since creating the opposing raw surfaces may lead to synechiae. If multiple procedures are carried out concurrently, the incidence of synechiae can be reduced by using splint during the surgical procedure.

26. Laser reduction of turbinates

Reduction of the hypertrophied mucosa and submucosa of a turbinate is the primary aim of turbinate surgery. However, the mucosa is lined by specialised respiratory epithelium with stratified ciliary epithelium that cleanses, moisturises, and warms the inhaled air. A compromise is sought by many workers, who stagger the extent of damage over the entire surface of the mucosa. A variety of methods has been used, all with the common aim of protecting as much as possible of the precious respiratory mucosa. Broadly speaking, these methods consist of the removal of vertical (Fig. 5) or horizontal (Fig. 6A, B) strips from the surface of the turbinate, rather than vaporising all the surface mucosa (Fig. 3B) and submucosa. There does not seem to be any particular reason for preferring either the vertical or the horizontal method. The surrounding tissue blanches and collapses into the groove, and visibly improves the airway. The width and depth of each strip are a matter of judgement for the individual surgeon, and these have to be tailor-made for each turbinate. The untreated intervening strip minimises the amount of overall destruction of the delicate respiratory epithelium and helps its rapid regen-

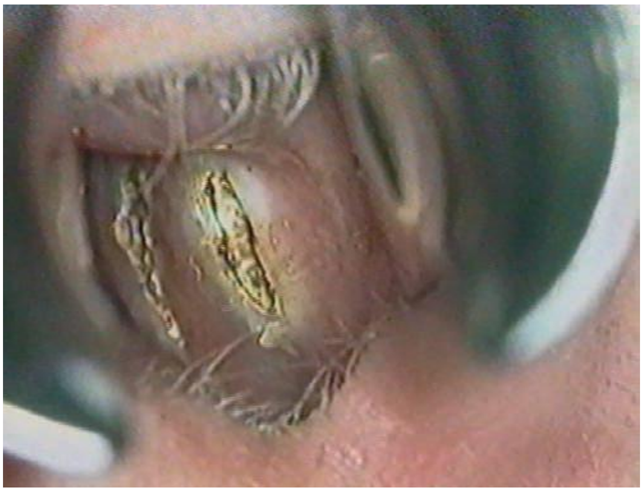
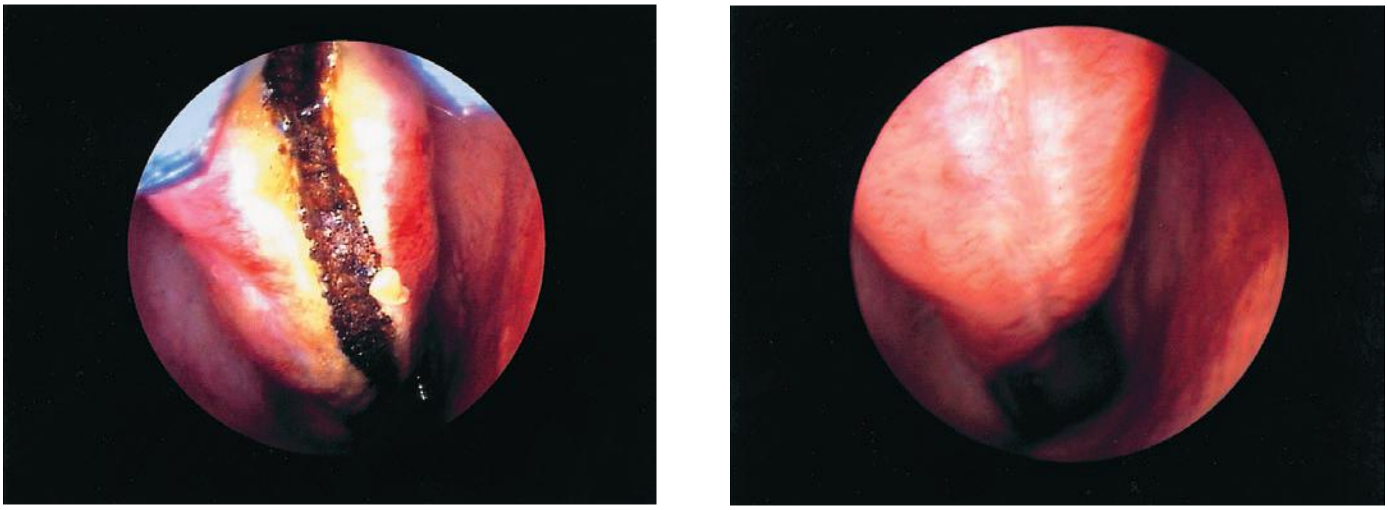
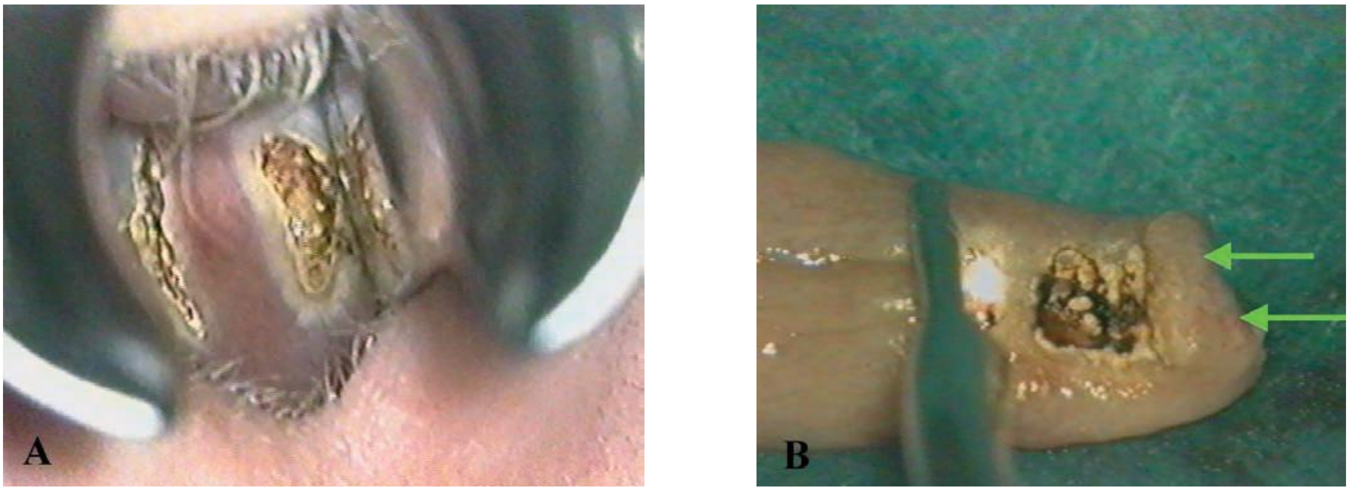


Fig. 5. Vertical strip removal (Ho:YAG laser).



A. B.

Fig. 6. A. Vaporisation for inferior turbinate with diode laser. B. The endoscopic view, 12 weeks after laser treatment, shows scarring of inferior turbinate. The nasal fossa shows improved airway. (Courtesy J. Hopf)



A. B.

Fig. 7. Ho:YAG laser vaporisation of vertical strips (A), 2-3 mm wide, with the ends of the strips extending superiorly and inferiorly as required. Note preservation of intervening normal mucosa. Strikes on fresh human turbinate shows shrinkage of the anterior end (arrows).

eration (Fig. 7A, B). The concept of submucosal application is also based on sparing the mucosal lining. The fibre is inserted through the mucosa in several places, and the laser is activated for a short time (Fig. 8). Submucosal application is the most suitable for allergic hypertrophy, since there is much oedematous tissue in the submucosa. In vasomotor rhinitis and rhinitis medicamentosa, there may be submucosal hyperplasia with very little space in the submucosa. In such cases, submucosal application may not be possible. The energy delivered should be in short bursts, so that the tissue is seen to *shrink* rather than to blanch (Fig. 9A,B).

Lenz (1985) used the argon laser to create a zone of coagulum, some 3-5 cm long, 2 mm wide, and 1-3 mm deep, from posterior to anterior. The coagulation layer is deepened by exposing it to further radiation. The result is that the central area of some 2 mm in width is now carbonised and, in turn, it is surrounded by a layer of coagulation, some 1-2 mm in width. The spot diameter of the argon laser is 1 mm.

Levine (1989, 1991) used the KTP/532 laser and combined vertical and horizontal strip removal, leaving small squares of normal-looking intervening mucosa approximately equal to the vaporised

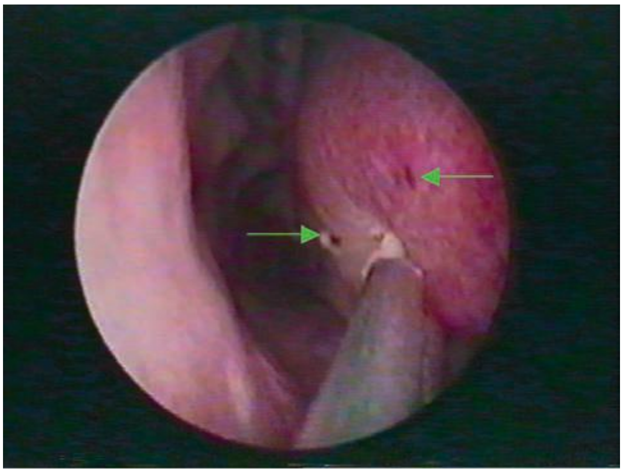


Fig. 8. Submucosal laser application at several discrete spots with diode laser.

area – the resulting appearance can be likened to a checker board.

Oswal used the Ho:YAG laser (1992) and prefers to remove vertical strips, 2-3 mm wide, with their ends extending superiorly and inferiorly as required (Fig. 10). Killian's speculum is then advanced so that its blade covers the vaporised strip and also adjoining normal mucosa of about the same width. This method has the advantage of effecting the reduction in a superior-inferior direction, where the hypertrophy is most marked. The posterior limit is reached when all the hypertrophied area has shrunk (Fig. 11).

Kunachak (1997) reported the use of the KTP laser in 50 patients in order to treat hypertrophy of the turbinate due to the allergic type of perennial rhinitis. The anterior one-fifth of the turbinate on one side was irradiated; the contralateral side was not treated, and acted as a control. Two months later, 90% of patients reported improvement in nasal blockage, itching, and rhinorrhoea. The depth and extent of surgery were not mentioned, neither was the state of the remaining fourfifths of the turbinate.

Kamami (1997b) used the CO_2 laser beam in the Swiftlase defocused char-free mode to resect the turbinate horizontally on its medial side, from the anterior to the posterior end. Any bleeding was controlled using bipolar coagulation. There were two cases of delayed bleeding. It is not clear how the defocused mode of even the Swiftlase remains char-free.

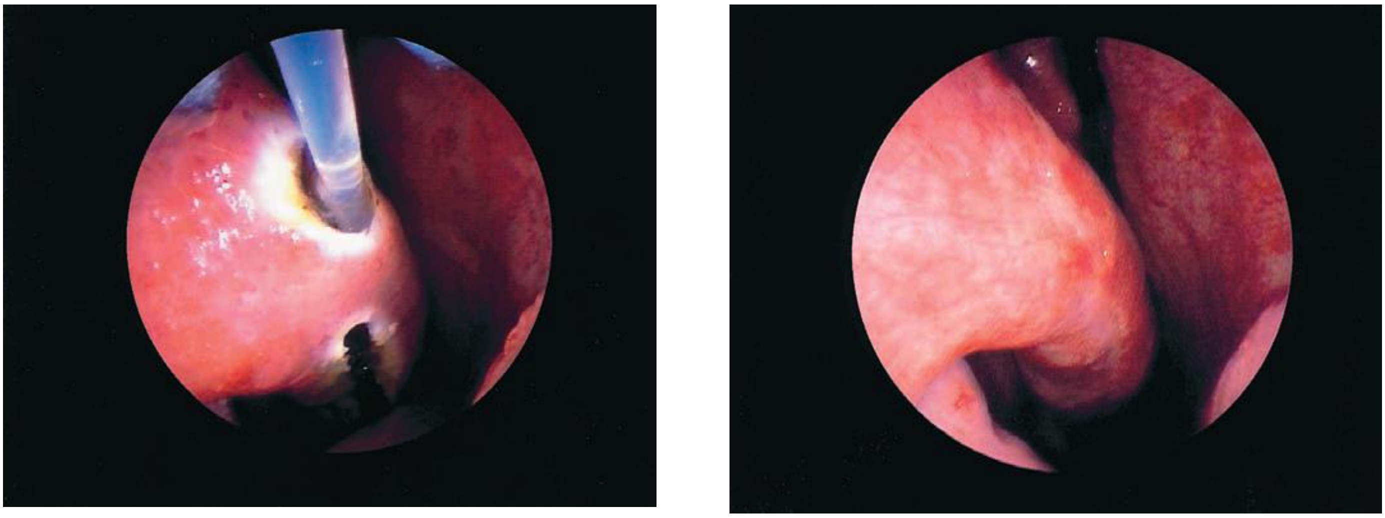
Ito (1997) used the Nd:YAG laser in the contact mode to irradiate 100-200 spots on the unilateral inferior turbinate in cases of perennial allergic rhinitis. The histopathology of the spots showed scar formation in the submucosa, but the mucociliary function was unaffected.

Fukutake *et al.* (1986) used the CO_2 laser to vaporise the entire surface of the anterior third of the inferior turbinate in allergic rhinitis cases. The laser was set at a 0.1-sec exposure time and 12 watts power. The total treatment time for the entire turbinate was one minute. Fukutake and coworkers maintain that, by using the CO_2 laser in this way, there is no risk of intraoperative bleeding. One treatment alone is not sufficient to relieve the symptoms, since it is so superficial. They have therefore devised a regime of fractionated treatment, once a week for five weeks and, at each session, treating increasingly deeper areas of the turbinate within the nasal fossa until the posterior end is reached. Since healing and regeneration of the mucosa takes two weeks, all subsequent treatments are carried out at intervals of less than two weeks. In this way, the mucosa is not allowed to regenerate until the treatment regime has been completed.

Vagnetti *et al.* (2000) used the Nd:YAG laser submucosally as a first step in the operation to reduce turbinates. This was followed by the removal of two strips of photocoagulated mucosa, side-by-side from the tail to the head of the turbinate. The objective was to achieve improved nasal patency, with a reduced complication and relapse rate.

27. Single or planned multiple sequential turbinate reduction

Most workers undertake maximum therapeutic reduction of the turbinate in the first instance. However, as already stated above, Fukutake *et al.* (1986) performed reduction once a week for five weeks. Kubota reported that more than 80% of patients required surgery only once, while the remaining 20% required a second procedure due to severity of their initial presentation. Thus, he sees the second procedure as part and parcel of the first, and uses the need for it to diagnose the severity of the disease! Certainly, patient compliance, cost considerations, efficient utilisation of resources, all such factors support the pretext that we should aim to complete the therapeutic reduction in the first procedure. There are no reports in the literature of any over-reduction leading to atrophic rhinitis or indeed necrosis of bony turbinates, although such a possibility must be borne in mind. Any unplanned revision surgery must be regarded as a failure of the primary procedure,



A.

B.

Fig. 9. A. Interstitial coagulation with a 940-nm diode laser at the anterior end of hypertrophied inferior turbinate. B. Endoscopic view 12 weeks after laser surgery. The anterior end of the inferior turbinate is reduced with good improvement in nasal airway. (Courtesy J. Hopf)

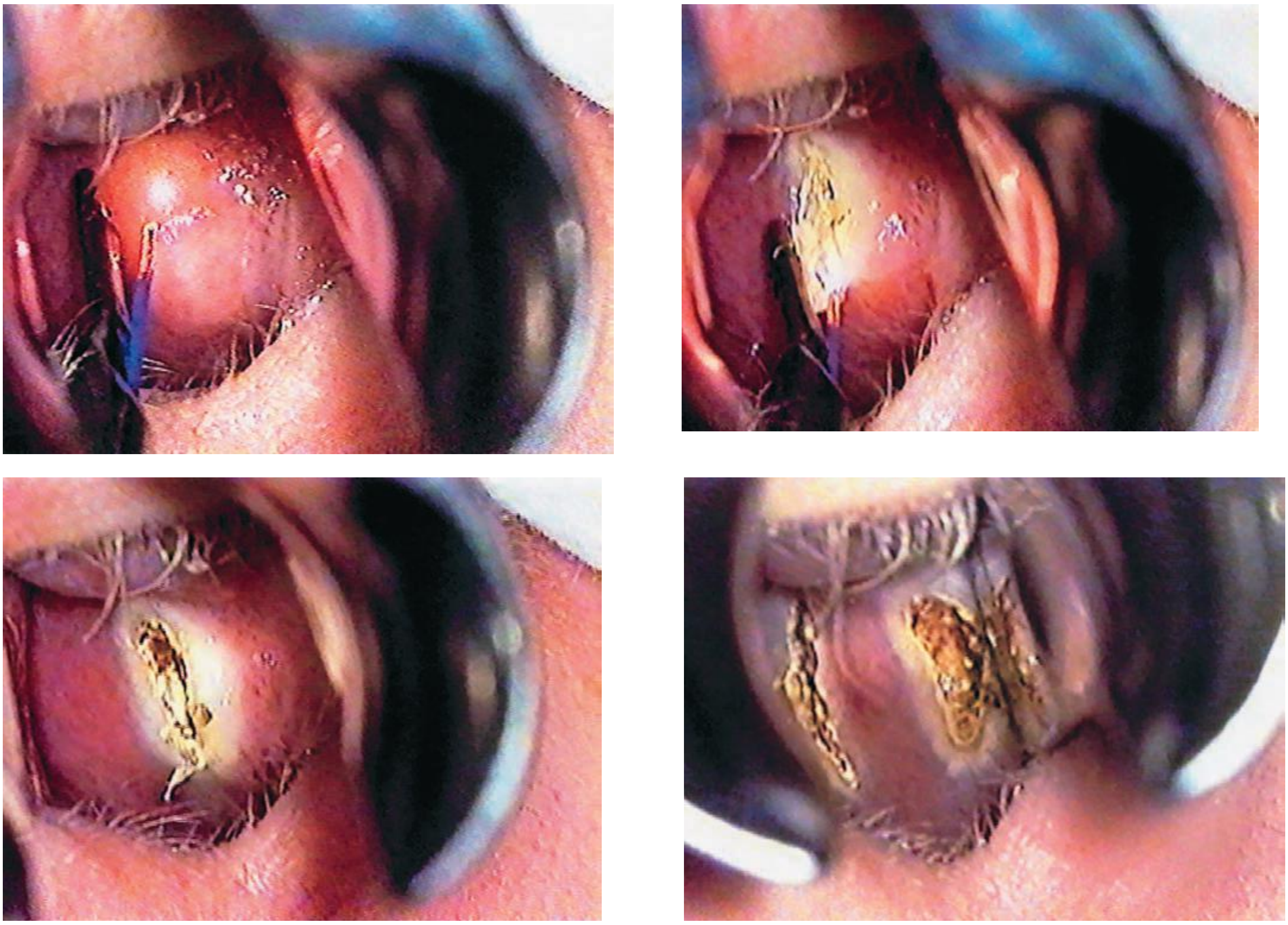


Fig. 10. Killian's speculum advanced so that its blade covers the vaporised strip and also adjoining normal mucosa of about the same width. This method has the advantage of effecting the reduction in the superior-inferior direction where the hypertrophy is most marked.

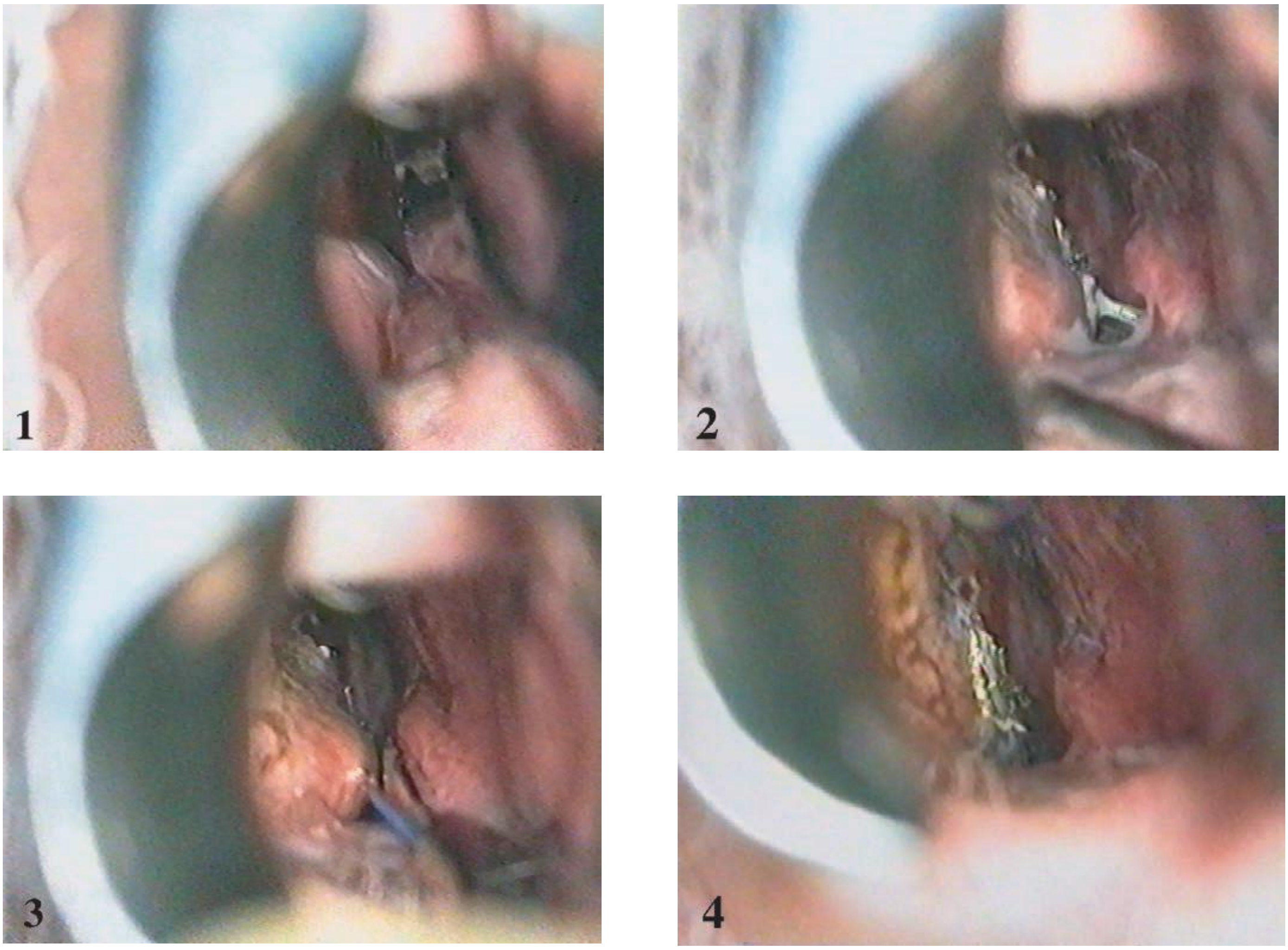


Fig. 11. The posterior end of the inferior turbinate is reduced with a few strikes until the oedematous tissue collapses.

and the cause be investigated as stated above. The failure may be due to inadequacy of the reduction, or the presence of contributing factors, or a combination of both. Such a policy will help individual surgeons to produce their own criteria in order to achieve overall long-term results.

28. Postoperative course

The postoperative course following laser turbinate reduction largely depends upon the wavelength, laser parameters, and extent of surgery undertaken. Generally speaking, lasers such as the KTP, which produce more coagulation and less vaporisation, will cause a greater inflammatory reaction, compared to that following the CO_2 laser. The nasal obstruction, rhinorrhoea, and crust formation will be prolonged. Inouye *et al.* (1999) observed that the inflammatory reaction lasted for up to four weeks with the CO_2, but was prolonged to eight to ten weeks with the KTP. In the experience of one of the present authors (VO), the Ho:YAG laser is both a good vaporiser and a good haemostat, on account of its high pulse energy. The 2.1 µm wavelength of the Ho:YAG is highly absorbed by water, and hence the depth of coagulation is relatively shallow, and consequently, the inflammatory reaction is much less. The crust separates within ten to 14 days and, in most cases, epithelial regeneration is complete at three weeks.

Following laser reduction of the turbinate, patients are remarkably free of any physiopathological burdens. Locally, there is no pain in the nose, and some patients perceive immediate improvement in their nasal airway.

Within 48 hours, site of the operation is covered with fibrinous exudate, which is replaced by eschar after a few days. The eschar dries with crust formation. Regeneration of the epithelium underneath results in separation of the crusts, which normally come loose between two to four weeks postoperatively.

Initially, there may be a watery, blood-stained discharge, which stops after three to five days. There are no reports of and, certainly in our hands, there has been no single incidence of postoperative reactionary or secondary bleeding.

At six weeks postoperatively, the healing is complete with regeneration of the epithelium. No granulations are seen at the operation site. Occasionally, synechiae may form between the septum and the turbinate. Septal perforation is an uncommon occurrence, and any such case should be thoroughly assessed to identify the cause, and steps taken to avoid its occurrence in other cases to be treated with a laser. A detailed discussion on synechiae formation and septal perforation appears later in this chapter under the heading ‘Patient risks’.

29. Changes in the histology of reduced turbinates

Inouye *et al*. (1999) studied the histological changes occurring between four and ten weeks after laser surgery on turbinates. The ciliary epithelium is replaced by stratified columnar or cuboidal epithelium. The lamina propria was replaced by fibroblasts and collagen fibres. Oedema, eosinophil infiltration, and the hyperplastic nasal glands completely disappeared. Interestingly, these changes persisted for more than two years in non-relapsed cases. However, in cases that showed no improvement in their symptoms of nasal allergy, no histological changes were present either. In relapsed cases, the epithelium remained ciliated, there was an abundance of eosinophils and glandular components in the lamina propria, which itself was intact and did not show any cicatrisation.

Elwany and Abdel-Moneim (1997) treated the enlarged inferior turbinates of ten patients suffering from chronic non-allergic rhinitis with a CO_2 laser. Tiny biopsies were taken, at the time of surgery as well as one month later, and were processed for electron microscopy. The ultrastructural observations showed early epithelial loss. However, this was followed by prompt regeneration of healthy epithelium, a decreased number and activity of the seromucinous glands, fibrosis of the connective tissue stroma, and a diminished number and congestion of the cavernous blood spaces. All ten patients showed complete improvement in nasal breathing.

30. Adequacy of the reduction of turbinates

With regard to the question of the adequacy of surgery, it is universal practice to decongest the mucosa prior to surgery on the turbinate in order to minimise intraoperative bleeding. Vaporisation is then carried out with the laser energy. The end point of surgery is difficult to judge since the turbinate has already been shrunk.

31. Outcome measure:

A range of criteria have been used to determine the outcome of laser reduction of inferior turbinate and an inevitable comparison with other surgical modalities:

31.1. Nasal obstruction

The most consistent benefit from turbinate reduction is the improvement in nasal airflow. Various methods have been devised to assess the benefit and to compare the results obtained with other methods of reduction.

31.1.1. Subjective improvement

Kunachak *et al.* (2000) reported on a cohort of 58 patients suffering from perennial allergic rhinitis. The anterior one-fourth of the inferior turbinate was ‘lased’ with a KTP laser on one side, the other side was untreated and acted as a control. Twenty months later, of 53 follow-ups, 81% of the patients reported good to excellent subjective improvement, while 16.6% had fair, and 1.8% poor subjective improvement of their symptoms.

The mean (± SD) degree of improvement in the treated and untreated sides was 77.1 ± 17.8% and 38.4 ± 29.4%, respectively; this was statistically significant ($p < 0.001$). This improvement could still be seen at the 20-month follow-up, and there were no complications. Kunachak concluded that a single minimally invasive KTP laser treatment for perennial allergic rhinitis was an effective approach, resulting in moderately long-term improvement.

If, after an apparent patent airway, patient continues to experience nasal obstruction then other causes should be considered, such as collapse of ala during inspiration, or narrowing of the isthmus. A bulbous posterior end may not have been reduced adequately. A hidden polyp in the middle meatus may have been overlooked. An isolated posterior spur is usually not contributory to the continuing symptom of nasal obstruction.

31.1.2. Patient satisfaction

A questionnaire enquiring patient satisfaction following laser reduction of inferior turbinate assures the surgeon that the laser approach can be continued for other similar patients. However, it should be noted that such an enquiry is a broad-brush approach, since the patient would always subconsciously include the whole experience of the event. The influencing factors are: general set up of the practice, staff attitudes, the fuller explanation of the course of the management rather than one-off treatment, the possibility of staging the operation, the probability of recurrence of symptoms and further surgery, the need to continue anti-allergic medication, the risk-benefit issues, and so on. A running commentary of the anticipation of the successive stages of the procedure goes a long way in securing patient confidence.

An enquiry for intraoperative pain or discomfort for office-based laser procedure under topical anaesthesia is a useful marker of patient satisfaction and word of mouth recommendation. Caffier *et al.* (2011) found that the overall patient satisfaction improved significantly with time ($p < 0.0005$).

31.1.3. Objective improvement

Elwany and Thabet (2001) measured the minimal nasal cross-sectional area in 149 patients treated with the CO_2 laser in the unipulse mode. They found that the cross-sectional area increased significantly from 0.52 to 0.81cm^2. The average decongestive effect decreased from 0.26 to 0.07cm^2, indicating significant laser-induced fibrosis.

Rhinomanometry is not routinely used, since its results and interpretation is not always accurate. However, it has a role in departments actively involved in research.

31.2. Anosmia

Symptom of anosmia due to the obstruction to airflow to the olfactory epithelium is obviously not permanent. It varies with the degree of the obstruction. Sense of smell is restored when the obstruction to the nasal airway is successfully treated. A note of caution: it is always advisable to enquire the state of sense of smell preoperatively and make a note, to avoid any claims that the anosmia resulted from the improper use of laser (or for that matter, non-laser) for nasal surgery, or application of topical anaesthesia.

31.3. Rhinitis medicamentosa

While both allergic rhinitis and rhinitis medicamentosa patients present with symptoms of nasal obstruction, the turbinate enlargement shows one important distinction in the two conditions. The turbinate in allergic cases is hypertrophied, boggy and oedematous. It quickly shrivels with decongestants and with laser strikes. However, the turbinate in rhinitis medicamentosa is hyperplastic. There is hardly any oedematous submucous tissue. The laser energy results in comparatively greater charring and the mucosa is difficult to vaporise. Systemic decongest medication may provide some relief but majority of cases are recalcitrant.

Caffier *et al.* (2008) undertook prospective study in a cohort of 41 patients with a diagnosis of rhinitis medicamentosa. The patients were treated with office based diode laser reduction of inferior turbinate for the symptoms of nasal obstruction. Preoperative addiction to decongestants was 5 ± 2 years (mean ± SD). There was significant improvement in nasal airway. A total of 88% of patients managed to successfully stop decongestant abuse after six months (74% after one year). They conclude that in cases of rhinitis medicamentosa, office based diode laser reduction of hyperplastic (as against hypertrophied) inferior turbinate represents a highly effective, safe, and well-tolerated treatment option that provides long-lasting recovery by stopping addiction to nasal decongestants.

32. Effects of turbinate reduction on the symptoms of nasal allergy

Nasal allergy results in symptoms of nasal obstruction, watery discharge, sneezing, and itching. The inferior turbinate is markedly hypertrophied. Most surgical treatments of the inferior turbinate aim at improving the symptom of nasal obstruction by reducing the turbinate to a ‘normal’ size. Very little is known about the effects on other allergic symptoms, such as rhinorrhoea, sneezing, etc.

Inouye *et al.* (1999) studied 204 patients with proven allergic rhinitis (according to Okuda’s classification), treated with laser reduction. They evaluated nasal patency using nasal ventilation tests and found that, in the majority of cases, there was good correlation between the symptomatic relief of the nasal obstruction and the results of ventilation tests. These workers observed cicatrisation in the lamina propria following laser surgery, and postulated that scarring did not allow the accumulation of fluid, due to dense collagen accumulation, and thus the mucosa did not become engorged, thereby producing relief from nasal obstruction. According to these authors, scarring of the lamina propria also has a number of other beneficial effects which improve allergic symptoms. Scarring reduces the blood flow and causes ischaemia, leading to a reduction of oedema. At some stage of healing, neovascularisation of the scar tissue will increase the local haemoglobin level to the extent that is found in non-allergic patients. Scarring also decreases the penetration of allergens deep into the mucosa, thereby reducing allergic reactivity.

Thermal damage to the autonomic nerve endings in the mucosa reduces sensitivity to allergens and thus provides improvement in the symptoms of sneezing and itching.

Inouye *et al.* (1999) also observed a reduction in the population of goblet cells in the lamina propria, studied pre- and postoperatively by light microscopy. They postulated that improvement in the symptoms of rhinorrhoea might be attributed to the reduction of the goblet cell population.

Symptomatic improvement of the severity of allergic reactions was attributed to regeneration of the mucosa with stratified cuboidal or columnar epithelium in place of the stratified ciliated epithelium observed preoperatively. Although allergens in the inhaled area did stick to the mucus, their invasion into the mucosa was much less due to a change in the epithelial type. In support of their observations, Inouye *et al.* quote the work of Fukutake *et al.* (1986) who observed suppression of the allergic response to the provocation test and eosinophil count in the nasal secretion, and correlated this to histological changes in the superficial layer of the mucosa, after laser reduction. Fukutake *et al.* used a CO_2 laser for turbinate reduction.

Kawamura *et al*. (1993) also used a CO_2 laser for reduction of turbinates, and investigated its effects on chemical mediators of the allergic response. They observed a decrease in eosinophil cationic protein (ECP) in the nasal secretion after laser surgery. This decrease was closely correlated to symptomatic improvement, and was thought to be the result of squamatisation and decrease in the penetration of the allergen into the mucosa after laser reduction.

Fukutake *et al*. (1986) measured the indicators of local haemoglobin levels in the nasal mucosa (IHb). IHb was significantly decreased in patients with allergic symptoms. However, after laser surgery on the turbinate, there was an increase in IHb level due to neovascularisation of the scar tissue, which was confirmed histologically.

Kawamura *et al*. (1993) measured blood-flow volume in the mucosa, and found that it was decreased in allergic rhinitis patients. The bloodflow volume further decreased in patients after laser surgery due to poor vasculature of the scar tissue, which helped to reduce engorgement of the turbinate.

Elwany (1997) studied 487 patients who had undergone turbinate reduction with the CO_2 laser. Of these patients, 382 had non-allergic and 107 allergic rhinitis. One year after surgery, 93% of the non-allergic and 71% of the allergic patients had maintained improvement in nasal breathing. Elwany concluded that the long-term improvement is much better in non-allergic than in allergic rhinitis patients. In common with studies by other workers, ultrastructural and histochemical examination showed that there was rapid regeneration of the epithelium, intense submucosal scarring, diminished activity of the glandular element in the submucosa, and diminished vascularity of the laser-treated area. However, the activity of the choline esterase enzyme was not diminished, indicating that laser treatment has no effect on allergic reactions.

Caffier *et al.* (2011) used diode laser in a cohort of 40 patients presenting with symptoms of nasal obstruction. The two groups comprised of perennial allergic rhinitis (pAR, n=20) and those who had seasonal allergic rhinitis (sAR, n =20). 95% patients had their inferior turbinate reduced, 40% required septal surgery whereas 15% underwent middle turbinate surgery. The assessment was carried out 1, 12 and 24 months postoperatively. It was based on relief of nasal obstruction, allergy symptoms and allergy tests. Two patients had considerable residual symptomatology. The maximum relief was obtained for nasal obstruction. For other symptoms such as rhinorrhoea, sneezing and itching, initial improvement was higher in pAR but more sustained in sAR. After two years 30% sAR and 40% pAR patients needed to continue or start standard anti-allergic medication due to recurrent allergy symptoms. The allergy disposition remained unchanged as shown by skin and in-vitro tests. They concluded that the office-based endonasal diode laser surgery appears to be effective, safe and well tolerated for treating patients who fail to show improvement following medical therapy.

There are very few studies which looked at objective evidence of beneficiary effects of laser surgery on allergic biomarkers. In a prospective randomized controlled study by Chusakul *et al.* (2011) one group received KTP laser reduction and the other group acted as control. Eosinophil count was assessed in nasal lavage from both groups on day 21 and at three months, after challenge with house dust mite. The KTP group showed a significant reduction in eosinophil influx (P = 0.013). They concluded that KTP laser surgery for reduction of inferior turbinates also reduces eosinophil influx after nasal challenge in perennial allergic rhinitis.

The work of these workers seems to indicate the following: laser treatment of allergic rhinitis results in:

- reduction in the bulk of the turbinate, thereby improving the symptoms of nasal obstruction;
- change in the surface epithelium from ciliated to stratified cuboidal or columnar, thereby reducing the sensitivity of the mucosa to allergens;
- cicatrisation in the lamina propria, which reduces the penetration and reactivity of the allergen. Cicatrisation also prevents accumulation of the oedema, thus improving the symptoms of nasal obstruction;
- thermal damage to the autonomic nerve supply of the mucosa helps reduce reactivity and helps the symptoms of sneezing and itching;
- the above hypotheses are supported by pre- and postoperation histology, electron microscopy, ventilation tests, blood flow tests, etc.;
- preservation of some ciliary-lined respiratory mucosa helps regenerate healthy new mucosa to cover the raw surface following laser surgery.

33. Surgical outcome

Reports on laser use for the reduction of turbinates continue to appear in the literature on a regular basis. Although the laser is being used with increasing ingenuity, it is important to appreciate that there are a number of variables in the tissue interactions of the various lasers and their parameters, which will influence both the immediate and delayed loss of mucosa, with eventual size reduction and cicatrisation. As a generalisation, failure to achieve short-term improvement in nasal obstruction results from either inadequate surgery or a contributory cause that was overlooked at the initial examination. Long-term failures are most likely to be related to allergic components which continue to influence the respiratory mucosa after apparently successful surgery.

The penetration of laser energy varies considerably with the wavelength used. The CO_2 laser has a very shallow penetration depth, while the Nd:YAG penetrates much deeper. The power setting and exposure time will also influence the eventual outcome. Mittleman (1982) used a power of 6-10W with the CO_2 laser, with a defocused beam giving a spot size of 1-2 mm, while Selkin (1985) used a 15-18 W continuous beam with a combination of a focused and defocused beam. Elwany and Harrison (1990) used a high setting of 20-30W with the defocused beam of the CO_2. Inouye *et al*. (1999) used 15W defocused continuous exposure "to vaporise as large an area as possible".

It is obvious that any comparisons of surgical outcome by these various workers, using the same CO_2 wavelength, will have to be judged with considerable caution. It may be that each surgeon monitors his own cases carefully and adjusts the power, exposure time, technique, etc., in order to achieve a predetermined outcome at follow-up after between one and three months. The outcome measures should not only include patient satisfaction, but also some objective measures. The latter is more difficult to achieve in everyday clinical practice on account of time and cost, let alone test-retest reliability.

Kawamura *et al*. (1993) found that, if the improvement was noted at one month after surgery, it persisted for two years or more in most cases, but nevertheless a small number did show a relapse. A good postoperative result at a review examination after between one and three months seems to ensure a good long-term result, and it may be that any surgical treatment of the turbinate should have this goal of achievement as its gold standard.

Fukutake *et al*. (1986) noted a relapse rate of 15% within one year after surgery, which was corrected with further surgery. In their opinion, this relapse rate was a result of insufficient surgery in the first instance.

A 16-year retrospective study by Warwick-Brown and Marks (1987) of 307 cases showed patient satisfaction of 82% at one month, 54% at one year, and 41% at one to 16 years. The type of procedure, which included outfracture, cautery, diathermy, and partial turbinate surgery, did not influence the drop in patient satisfaction. In their view, this finding confirms the continuing dynamic role of the inferior turbinate in nasal breathing, rather than the poor long-term surgical outcome!

The most consistent improvement – short-, medium- or long-term – is in the symptoms of nasal obstruction. This is undoubtedly due to removal of the bulk of the obstructing oedematous mucosa by vaporisation, shrinkage by coagulation and cicatrisation. If the nasal obstruction fails to improve in a postoperative period of, say, three months, then further assessment must be carried out. In our experience, the following are some of the causes of the inadequate outcome of laser surgery for nasal obstruction:

- *learning curve:* inexperienced surgeons may find it difficult to use the laser, remove the smoke and debris, and control bleeding, particularly in the narrow confines of an obstructed nose;
- *free-beam CO_2 laser surgery:* it is relatively difficult to achieve satisfactory clearance of the posterior nose with the free-beam CO_2 laser;
- *preoperative use of decongestants:* the preoperative use of decongestants to reduce intraoperative bleeding shrinks the turbinate. It is then difficult to accurately access the extent of surgery necessary to improve the airway;
- *compression of allergic turbinate with a Killian speculum:* insertion of a Killian speculum can exert enough pressure to cause compression of boggy, allergic turbinates and give an erroneous impression of adequate reduction;
- *continuing allergic response:* in severe cases of allergic rhinitis, it is necessary to continue anti-allergic treatment after surgery in order to reduce the allergic response. In refractory cases, the authors have seen recurrence of enlargement of turbinates in a matter of weeks, despite adequate reduction and anti-allergic treatment. Vagnetti *et al.* (2000) treated 121 patients with the Nd:YAG laser in a two-step procedure: initial interstitial coagulation was followed by removal of strips of coagulated mucosa. At the one-year follow-up, the complication rate was 'very low'. A nasal patency of 85.9% was achieved at 12 months. In 65% of the relapses, the turbinate hypertrophy was due to allergic rhinitis;
- *associated pathology:* some patients complain of continuing nasal obstruction despite a good patent lower half of the nose showing an unobstructed view of the postnasal space. In such patients, there may an associated pathology that was not apparent initially because of a grossly enlarged obstructing turbinate. High deviated nasal septum, enlarged middle turbinate touching the septum, polyp in the middle meatus, which was not apparent initially because of an enlarged inferior turbinate, alar collapse, enlarged adenoids in adults, are some of the other causes for the inadequate outcome of turbinate surgery, not unique to laser usage.

34. Patient risks and benefits

It is appropriate that any surgical procedure should be assessed and evaluated for patient risk as well as benefit. The practice of modern day medicine will not be complete unless these risk and benefit factors are discussed with the patient, and informed consent is obtained.

34.1. Patient risks

A well planned laser turbinate surgery has very little risk associated with it. Most reports confirm improvement in the symptom of nasal obstruction. Intra- or postoperative bleeding event is rare with the laser surgery and probably does not warrant its mention as a possible risk factor while counselling. Benefits in respect of allergic symptoms are unpredictable, so is the need for continuation of anti-allergic medication.

Synechiae
Synechiae or fibrous bands may occur between the surface of reduced turbinate and the septum. These are usually symptom-free, but some patients may feel restriction to breathing. Synechiae only form if opposing surfaces are traumatised and a raw area is inadvertently created. Trauma to the septal mucosa may occur due to instrumentation. It may also occur due to thermal damage from flying charred debris. Thermal damage may not be apparent at the time of surgery. However, within 24–48 hours after surgery, slough is seen to form and covers the raw area. Fibroblasts proliferate and lay down fibrous tissue, which leads to the formation of synechiae. Damage to the septal mucosa can be avoided by placing a nasal splint against the surface of the mucosa. This splint is held in position by a Killian speculum. Removal of slough a few days after surgery is said to reduce the incidence of synechiae.

Septal perforation
Septal perforation is a rare event following turbinate surgery. It is more likely to happen if the septal

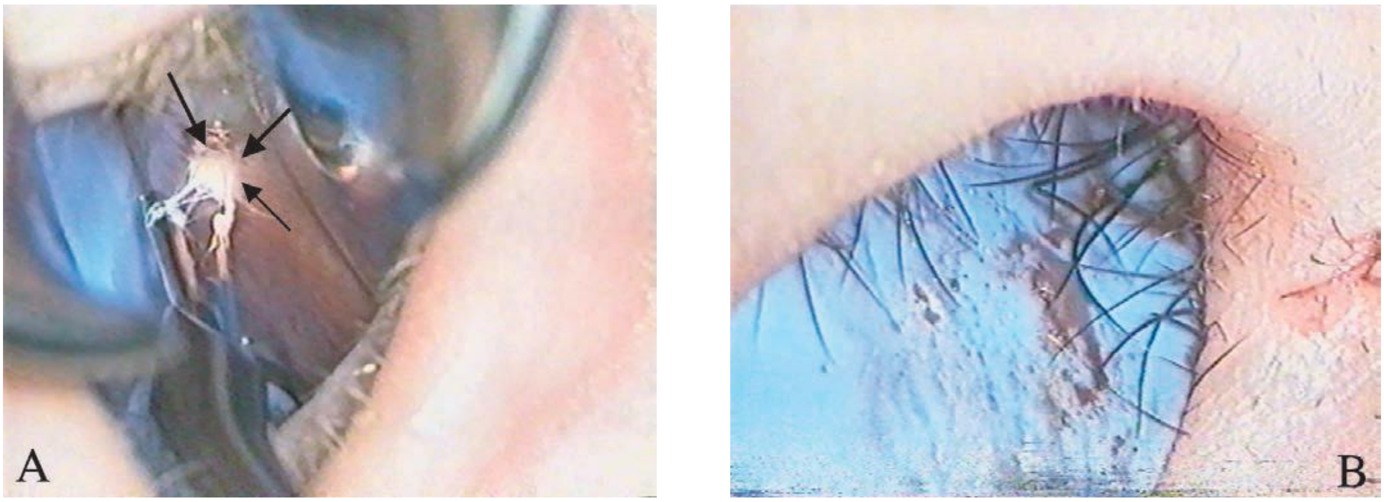


Fig. 12. A, B. Septal perforation can be totally avoided by protecting it with silicon nasal splint (A). Debris covering the silicon splint following reduction of inferior turbinate with Ho:YAG laser (B).

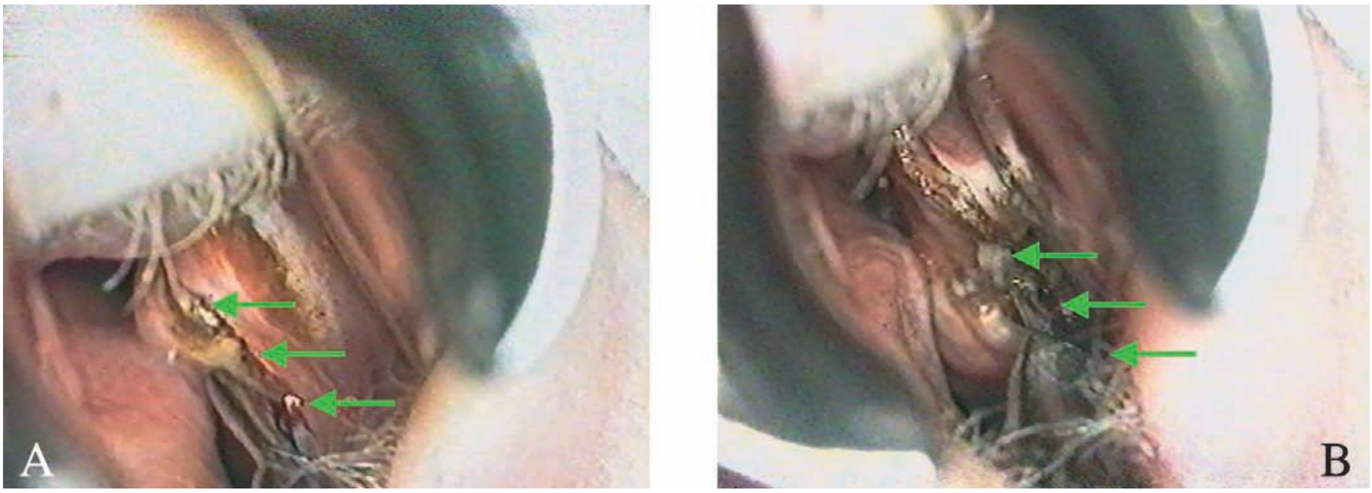


Fig. 13. A, B. In the presence of a spur touching the turbinate, the septal damage can be avoided by submucosal application of the laser energy.

mucosa is stretched over the convex deviation of the septum. Thus, it may be very thin and be damaged with instrumentation. However, unless the mucosa on the other side also suffers simultaneous damage, perforation will not occur. Flying hot debris from the turbinate may lead to thermal damage and necrosis of the mucosa. The blood vessels of the mucosa and the perichondrium shrink, and the cartilage suffers avascular necrosis which leads to septal perforation. This can be totally avoided by protection with a silicon nasal splint (Fig. 12A, B), the flammability of which should be tested at various wavelengths and energy settings. In the presence of a spur touching the turbinate, septal damage can be avoided by submucosal application of the laser energy (Fig. 13).

Empty nose syndrome

Excessive or over-zealous removal of inferior and/or middle turbinate leads to atrophic rhinitis, particularly in tropical countries, where the air is hot and dry. 'Empty nose syndrome' results in much crusting and foul smell. Symptoms of nasal obstruction actually worsen due to lack of proprioceptive sensation of flow of air. Scheithauer (2010) presented results derived from an actual in vivo study of airflow in "empty nose" patients and, advises caution and proposes surgery restricted to anterior turbinoplasty

Venous air embolism

The two reports on venous air embolism (VAE) are worth noting for awareness and prompt action. Osti *et al.* (2009) report a suspected case of VAE following the use of CO_2 laser probe for uvulopalatoplasty (UVPP) and turbinate surgery. High flow / high pressure gas was used to cool and clean the distal end of the CO_2 laser probe. The patient suffered cardiac arrest but was successfully resuscitated. They warn awareness, use of liquid instead of gas and vigilance to undertake resuscitation promptly should this unfortunate event occur.

Aqil *et al.* (2008) reported a case of venous air embolism leading to cardiac arrest, during submucous application of Nd:YAG laser. According to them, venous air embolism has also been reported during nasal sinus surgery and surgery for choanal atresia with Nd:YAG laser. They warn that there should be awareness of this serious risk, irrespective of the duration and the minor nature of the surgical procedure.

Fortunately, VAE is a rare event during nasal surgery.

Continuing nasal obstruction
The possible causes of continuing nasal obstruction have been discussed earlier.

34.2. Patient benefits

The major advantage of laser turbinate surgery is the lack of intraoperative bleeding, which allows an unobstructed view of the surgical progress. The laser procedure is minimally invasive, since it is possible to remove only the obstructing tissue, thus sparing the functioning respiratory epithelium. Unlike SMD, the spread of energy in the submucosa can be controlled by varying the parameters of the beam. Finally, postoperative packing is not necessary in the vast majority of cases. This avoids considerable discomfort to the patient, who can be treated in the office, or as an ambulatory day case. The postoperative oedema and crusting is minimal, and the improvement in nasal obstruction is noticed by the patient within a week or two. The period of absence from work is short.

35. Alternatives to laser for turbinate surgery

On the basis of minimising the damaging effects on the muco-ciliary transport system and also to limit the deeper coagulation of the mucosa, alternative methods for reduction of turbinates have been used by some workers.

35.1. Radio frequency

Cassano *et al.* (2010) and Sapçi (2003) advocate the use of less damaging radiofrequency (RF). Sapçi *et al.* (2003) compared the effects of radiofrequency tissue ablation, CO_2 laser ablation, and partial turbinectomy on nasal mucociliary functions. They found that radiofrequency tissue ablation to the turbinate was effective in improving nasal obstruction objectively and in preserving nasal mucociliary function. However, while laser ablation of the turbinate was also effective in improving the nasal obstruction, it disturbed the mucociliary function significantly. Partial turbinectomy technique results were similar to the results with the radiofrequency tissue ablation technique.

Proponents of mucosa sparing technique would be reassured that their case has a histological proof. Zborayová *et al.* (2009) presented histological studies in pigs to demonstrate that diode laser produces more intense destruction and therefore inflammatory reaction in comparison to radiofrequency. The postoperative pain with diode is therefore more and the healing process, slower.

35.2. Cold instrumentation

Cassano *et al.* (2010) compared the effects of cold instrumentation versus laser surgery on the airway resistance, mucociliary transport time (MCTt) and the nasal cytology. They found that in both groups, there was reduction in airway resistant. However, MCTt was significantly shorter in endoscopic turbinoplasty than in laser turbinoplasty ($p < 0.05$). The number of altered ciliated cells had increased in the laser-assisted turbinoplasty-treated group but decreased in the endoscopic turbinoplasty-treated group. This endoscopic turbinoplasty group also showed a significant improvement in the goblet-to-ciliated cell ratio ($p < 0.01$). They conclude that, although both modalities result in improvement of nasal airway, the endoscopic turbinoplasty technique has an added advantage of preservation of nasal function.

35.3. Argon plasma coagulation

Argon plasma coagulation (APC) involves the use of argon gas, which is delivered as a jet via a probe. The gas is ionised by a discharge of high voltage electric current. High frequency electric current is then conducted through the jet of gas to the target and results in coagulation of the tissue. Iwasaki *et* *al.* (2010) used Argon gas coagulation to reduce the bulk of the inferior turbinate in 41 patients suffering from perennial allergic rhinitis (pAR) and reported a 24-month follow up. The main criteria of success were improvement in the symptom of stuffiness and impairment in daily activity. Nasal stuffiness improved in 90% of patients during the follow up period of 24 months. Impairment in daily activity also showed similar improvement. Of the 41 patients 18 (43.9%) did not require any additional treatment. A second APC treatment was administered to 10/41 (24.4%) patients during follow-up period. Additional anti-allergic medication was required in 15/41 (36.6%) patients. They concluded that APC provides a useful modality for the relief of nasal stuffiness and impairment in daily activity in cases resistant to medical management.

35.4 Microdebriders

Microdebrider has also been used. Kim (2010) found it particularly useful for removing bony turbinate hypertrophy, which is to be expected, since bone has very little water content and use of laser results in excessive charring.

36. Discussion

Laser turbinate reduction is a useful addition to the surgical management of nasal obstruction due to hypertrophied turbinates of various aetiology. With conventional mechanical methods, some 8% of turbinectomy patients have postoperative haemorrhage and, in 1%, this is severe. Compared to this rather serious risk to the patient, laser surgery is almost bloodless and, due to the lack of postoperative nasal packing, has a very low morbidity. The surgical outcome, with adequate workup, is predictable.

In allergic rhinitis, the initial management is medical. Refractory cases need surgical management to relieve the nasal obstruction. Inouye *et al.* (1999) consider that surgical treatment of the mucosa of the inferior turbinate should be used for a variety of allergic phenomena, such as nasal obstruction, sneezing, rhinorrhoea, itching, etc. They postulate the mechanism, quote several workers in support, and undertake a variety of objective tests to confirm that laser treatment has a beneficial effect on a whole range of allergic rhinitis symptoms, not just on nasal obstruction. However, none of these workers go as far as saying that the beneficial effects are specific to laser turbinate reduction. Thus, they may be equally apparent following thermal damage caused by submucous diathermy or cryosurgery. Randomised double-blinded trials would be valuable, but may be unethical in units where lasers are available. Multicentric trials from units with and without lasers could produce valuable information by undertaking prospective studies with an agreed protocol.

Laser surgery for turbinate reduction presents a significant advance in postoperative morbidity. The long-term results in non-allergic rhinitis cases are encouraging, although in allergic rhinitis, they are not as apparent on account of the continuing aetiology.

A major disadvantage of laser technology is its high capital outlay and stringent safety requirements. Radiofrequency equipment is comparatively cheaper and safer, and is making a steady inroad into the management of certain conditions. Rhee *et al.* (2001) compared temperature-controlled radiofrequency tissue volume reduction (RFTVR) with turbinate laser vaporising turbinoplasty (LVT). Sixteen patients underwent RFTVR and eight, LTV. The pre- and postoperative nasal functions were investigated by a visual analogue scale of symptoms, butanol threshold test, saccharine test, acoustic rhinometry, rhinomanometry, and ciliary beat frequency. At eight weeks postoperatively, the severity and frequency of the nasal obstruction had improved subjectively in 81.3% and 93.8% of the RFTVR group and in 87.5% and 87.5% of the LVT group, respectively. Interestingly, improvement in nasal symptoms began within two to three days after RFTVR, whereas there was a delay of eight weeks after operation in the LVT group. No reason was given for this finding. Saccharin transit time and ciliary beat frequency were preserved after RFTVR. Rhee *et al.* conclude that RFTVR is a viable and cheap alternative approach for the treatment of chronic turbinate hypertrophy.

In conclusion, the past couple of decades' literature review shows that lasers have secured a place for treating nasal obstruction secondary to the turbinate hypertrophy. The leading symptom of nasal obstruction improves, however, the results on the accompanying allergy symptoms is, at best, unpredictable. Office-based procedure is viable and cost effective. Diode seems the most preferable laser for this setting. Although the procedure is comparatively minor and risk-free, the two reports of venous air embolism are disturbing and worth the awareness for prompt action.

There is no doubt that the surgical management of enlarged turbinates is continuing to evolve.

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Manufacturers: Oswal suction fibre cannula. JB. Masters Ltd, Dorset Avenue, CLEVELEYS, Lancashire, FY5 2DB England

MCQ – 22. Nasal turbinate surgery

1. Instantaneous volumetric reduction of hypertrophied turbinate can be undertaken with
   a. A pair of scissors
   b. Submucous diathermy
   c. Submucous laser application
   d. Surface laser application
   e. Surface application of electro cautery

2. Postoperative inflammatory response is marked with the use of
   a. A pair of scissors
   b. Submucous diathermy
   c. Submucous laser application
   d. Surface laser application
   e. Surface application of electro cautery

3. Which of the following lasers are used in laser turbinate surgery on account of maximum absorption of laser energy by pigment in the blood, resulting in bloodless procedure?
   a. CO_2 laser
   b. Ho:YAG laser
   c. KTP laser
   d. Diode laser
   e. None of the above

4. Which of the following laser/s is/are not suitable for turbinate hypertrophy involving the whole length of the turbinate
   a. CO_2 laser
   b. Ho:YAG laser
   c. KTP laser
   d. Diode laser
   e. Nd:YAG laser

5. Submucous diathermy has the following advantages
   a. It is extremely cost effective
   b. Its energy delivery can be precisely controlled by observing the blanching of the tissue
   c. It is associated with very little post-operative oedema
   d. It is bloodless
   e. It is suitable for bony hypertrophy of the turbinate

6. With the surface application of laser energy
   a. The depth of thermal penetration depends on the wavelength of laser used and its parameters
   b. There is intraoperative bleeding which requires packing
   c. There is a significant damage to the ciliary transport mechanism, leading to crusting
   d. Nd:YAG laser may result in atrophic rhinitis due to deep scatter of its energy
   e. The inadvertent spread of energy to the septum may lead to septal perforation

7. With the submucous application of the laser energy
   a. There is no intraoperative or postoperative bleeding
   b. There is blanching of surface mucosa indicating spread of energy to the surface
   c. Oedematous mucosa is effective reduced without fibrosis

- d. The laser is effectively used to relieve the symptoms of nasal obstruction secondary to rhinitis medicamentosa
- e. The results are similar to the conventional diathermy method in cases of allergic rhinitis

8. In comparison to cold instrument surgery
    - a. Laser surgery is bloodless
    - b. No postoperative packing is required
    - c. Specific areas of enlargement can be targeted due to an obstructed view resulting from bloodless nature of the procedure
    - d. Controlled amount of energy results in very little postoperative oedema, adding to quick recovery
    - e. The laser surgery can be undertaken under local anaesthesia as an office based procedure, thus significantly reducing costs
    - f. All of the above

9. Laser turbinate surgery is not suitable
    - a. In the presence of deviated nasal septum
    - b. In patients with polypi
    - c. In cases of nasal obstruction due to atrophic rhinitis
    - d. In cases of snoring
    - e. In cases where nasal obstruction is due to alar collapse

10. Postoperatively, laser turbinate surgery
    - a. Is remarkably free from morbidity
    - b. Is painless
    - c. Results in much quicker symptomatic improvement when compared to submucous diathermy
    - d. Still requires anti allergic medication to control symptoms of allergy
    - e. Can be repeated in cases of recurrence of hypertrophy
    - f. All of the above

Chapter 23

Laser-induced microbial reduction in acute bacterial rhinosinusitis

J. Krespi and V. Kizhner

1. Introduction

Otolaryngologists were amongst the first to introduce laser technology in clinical practice in the latter half of the last century. The lasers were used as refined thermal knife, to excise the target tissue.

The clinical use of Near-Infrared Laser Illumination (NILI) for would healing is rapidly gaining ground in a number of specialities. However, its use in Otolaryngology is sparse. NILI has a dual role in wound healing. It modulates cells involved in tissue repair. It also slows down bacterial growth, thereby reducing the flora.

These effects are dependent upon exposure time and irradiance. Proliferation of various cell models varies according to the level of irradiance. It is also possible to expose the tissues to a lower irradiance with the use of photo-sensitising agent (PA).

Bacterial inhibition also depends upon a range of laser wavelengths, used singly or in combination, simultaneous use of photo-sensitizer, and different irradiance and radiant exposures settings (Nussbaum, 2003).

Chronic rhinosinusitis (CRS) is a prolonged and disabling condition in a number of adult patients. Functional Endoscopic sinus surgery (FESS) offers a considerable relief in significant cases. However, FESS fails to provide a lasting relief in a small number of patients.

Studies indicate that following a single surgical procedure of FESS, the revision procedure tends to be less successful. There is also an increased incidence of postoperative bacterial infection (Jiang and Hsu, 2002).

A medical management of failed FESS consists of antimicrobial and anti-inflammatory therapies. Anti-inflammatory medication such as local or systemic steroids, along with other immune modulating drugs such as leukotrien inhibitors, do not show long term promise (Magnusson *et al*., 1995).

The increased rate of MRSA infections and the presence of MRSA biofilms have resulted in further concern. Staphylococcus aureus has been implicated as one of the most common organisms causing CRS (18.6-36.6%).

In 9.22% cases of CRS, methicillin (or multi-drug) resistant S. aureus is implicated. A comparison of the rates of recovery of MRSA between the periods 2001-2003 and 2004-2006 in acute and chronic maxillary sinusitis illustrated a significant increase from 27% to 61% of all Staphylococcus CRS infections.

2. Mechanisms of microbial killing and inflammation reduction with NILI

Numerous *in-vitro* and *in-vivo* studies support the effect of NILI in surface microbial killing based on the following mechanisms:

- Anti-inflammatory

Laser effect was shown by a review article to induce apoptosis of polymorphonuclear cells and the respiratory burst of neutrophils, all desirable therapeutic effects in CRS related mucosal inflammation (Abels *et al*., 2000). Recently, indo cyanine green, ICG was investigated as an active agent in the treatment of several cancers such as melanoma and breast (Sobanko and Alster, 2008). Additional successful stud-

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ies treating acne vulgaris (in itself a disease with an inflammatory contributing pathphysiology) with photoactivated ICG showed great promise (Tuchin *et al*., 2003).

- Anti-bacterial

Antibacterial mechanisms include light mediated bacterial killing based on two factors, free radicals generated by the light-activated PA, and heat generated by the laser activation. According to the seminal discovery of Neuman while using optical traps for detecting microbial movements, NIR illumination at specific wavelengths was found to be profoundly bacteriostatic (Nussbaum *et al*., 2003).

Laser microbial killing effect has been a focus of numerous studies. Krespi has shown the safety and efficacy of a 940 nm NIR in treating acute bacterial rhinosinusitis pathogens including Staph aureus and Pseudomonas (Krespi *et al*., 2009).

Staph and Pseudomonas are among the most widely studied bacteria susceptible to laser eradication due to their abundance in chronic wounds, and, as a result, laser treatment for chronic wounds is becoming increasingly accepted (Meltzer *et al*., 2006). Guffey showed the combined effect of 405 nm and 880 nm lasers can reach eradication of 72% of the Staph and 94% of Pseudomonas with fluency of 20J/cm^2 (Guffey and Wilborn, 2006). Using an 810 nm, Nussbaum proved that Pseudomonas killing depends on irradiance and exposure time. Thus, with three treatments at radiant exposure of 1-2 J/cm^2, the bacterial load could be reduced to 27% of pre-irradiation values (Nussbaum *et al*., 2003).

3. Mechanism of action

A proposed mechanism of action for potentiation of antibiotic was shown to be absorption of photoenergy by bacterial chromophores, leading to a decrease of plasma membrane potential in bacteria, with additional generation of free oxygen radicals. A human pilot study of MRSA carriers in the nasal vestibule showed reduction of up to two logs in the bacterial load.

The optical effect and heat generated by laser illumination by itself will reduce the colonies formed by Staphylococcus aureus, Klebsiella pneumoniae and Pseudomonas aeruginosa, thus potentiating the effect the laser, with or without a PA agent (Magnusson *et al*., 1995). During NILI therapy the surface tissue temperature rises up to 10-12 degrees Fahrenheit from baseline (Morgan and Rashid, 2009). In similar studies using a 930 nm laser the temperature elevation was well within physiologic limits (Bornstein *et al*., 2009).

4. Which laser?

The 940 nm laser as a single laser therapy simplifies the addition of laser treatment of CRS refractory to surgery. The 940 nm eliminates the need for a PA while still achieving the goals of NILI. Moreover, due to its wavelength, the penetration of scarred tissues delivers NILI beyond its visible treated area. While usage of PA is limited to its delivery (most PA are activated at lower wavelengths) the 940 nm diode laser bypasses this obstacle. The 940 nm was shown to be equally effective in treating ABRS (acute bacterial rhino-sinusitis) when compared to laser+PA. The 940 nm was also shown to be safe to the ciliary mucosa in histologic studies. It has also shown great promise in targeting MRSA as a single modality therapy. Safe and efficacious laser therapy methods in acute rhinosinusitis (animal and in vitro study) with its ability to treat and control MRSA were outlined in previous studies (Krespi *et al*., 2010; 2009). The safety of NILI was shown to be not only histologically but also by retaining mucosal function as well. In a human study treating end stage CRS patients, a saccharine study performed at the conclusion of the treatment showed normal function.

As patient comfort is of utmost importance, it is noteworthy that side effects were minimal and short lived, considering that the debridement treatment is performed in the office setting. At this point in time, as paediatric or pregnant patients were not involved in any human study, we cannot recommend NILI in this patient group.

5. Laser setting

The laser energy should be delivered with a two m long, 400 or 600µ core diameter cylindrical diffuser fibre with an active illuminating tip of 30 mm, (Light Guide Optics, Rheinbach, Germany) allowing uniform circumferential cylindrical light emission. Power is set at four W maximum (based on the criteria of previous studies: Krespi *et al*., 2010; 2009) in continuous mode. All laser activation was performed after application of a topical anaesthetic mixed with a vasoconstrictor. Patients were treated in an office-based setting, in a semi-sitting position, with eyes protected with laser safety goggles. The laser is activated for approximately three to four minutes, delivering around 500 joules per side, depending on the patient's tolerance of intranasal heat sensation. Occasionally, the application was intermittent, for better tolerance. The extent of the treatment is based on the clinical severity of the patient's symptoms, endoscopic findings, the symptoms severity assessed with a SNOT20 score and the response. The illumination treatment was performed two or three times (based on response, with the better responders receiving only two treatments), with approximately five days between laser illuminations.

6. Results

As it is wise to culture the nose before the treatment begins, it is not necessary to continue culturing the patient until the treatment is over. Improvement in nasal symptoms is expected in a week of completing treatment. Results are sustained for several weeks and the treatment can be repeated safely.

7. Conclusions

NILI of the nasal sinuses is beneficial both subjectively and objectively in CRS patients with failed medical and surgical therapies. NILI is safe, reproducible, sustained and appears not to interfere with ciliary motility. Due to the antimicrobial action of the NILI and its ability to modulate wound healing, exacerbations of CRS symptoms can be avoided without using antibiotics and steroids for up to six months. It is possible that additional use of topical or systemic antibiotics effect can be potentiated with NILI, however, such an effect remains to be proven. Likewise, unlike the proven role of antibacterial therapy, the role of the illumination therapy as an additional modality in the routine management of CRS is yet to be conclusively determined.

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MCQ – 23. Laser-induced microbial reduction in acute bacterial rhinosinusitis

1. Laser illumination killing of surface microbacteria is based on
    a. Increased immune response
    b. Photo-disruption of bacterial structure
    c. Anti-inflammatory action
    d. Photo-sensitisation of bacteria enhancing effects of antibiotics.
    e. All of the above

2. Surface microbacterial killing is achieved by using
    a. Near-Infrared laser illumination
    b. Mid-Infrared laser illumination
    c. Far-Infrared laser illumination
    d. Intense pulse light
    e. All of the above

3. In resistant cases of rhinosinusitis
    a. Laser illumination of the nasal sinuses is beneficial both subjectively and objectively in CRS patients with failed medical and surgical therapies.
    b. Laser illumination is safe, reproducible, and does not interfere with ciliary motility.
    c. Exacerbations of CRS symptoms can be avoided without using antibiotics and steroids
    d. Additional use of topical or systemic antibiotics effect can be potentiated with Laser illumination
    e. All of the above

4. Normal ciliary function
    a. Is temporarily affected by laser illumination
    b. Is unaffected by laser Illumination
    c. It is uncertain if the function is affected at all
    d. It is adversely affected in children and hence laser illumination should not be used in children
    e. Extent of the damage is dependent up on the severity of infection

Chapter 24

Laser-assisted functional endoscopic sinus surgery

S. Kaluskar, J.U.G. Hopf, M. Hopf and H. Scherer

Editors' note: Endoscopic surgery for the management of diseases affecting the nose and the paranasal sinuses is now universally practised. The introduction of laser technology and dedicated instruments has added a further dimension. However, lasers are not just another design of the existing cold instruments. The effect of lasers on the various tissues is far reaching, beyond the visual effect. Laser effects are dependent upon the wavelength, its delivery, the parameters of the beam, and the method of application to the target tissue. Finally, it must be emphasised that, just as in cold-instrument surgery, it is the operator who controls the ultimate outcome of the laser application. Therefore, it is necessary that the laser operator acquires this new level of skill and proficiency before embarking upon its endonasal use.

There is no one specific laser that is most suited for endonasal application. As the technology developed, a number of wavelengths were introduced and most were found to be suitable for endonasal surgery. However, their tissue interaction is far from uniform and it would be inappropriate to substitute one wavelength for another, without good reason. This state of affairs may be confusing for the established, as well as for the new user. In order to address this issue, the editors took a deliberate decision to invite contributions from two sources in order to cover the range of wavelengths. It is therefore inevitable that there will be some repetition. Their individual opinion is identified by inserting the initials in brackets. The contents of this chapter are focused on clinical issues in laser surgery relevant to functional endoscopic sinus surgery. The reader should refer to Chapter 20, Endonasal laser applications, for the core knowledge of lasers in endonasal surgery.

Part A

S. Kaluskar

1. Introduction

The last decade of the last century saw the wide acceptance of endoscopic sinus surgery (ESS) and functional endoscopic sinus surgery (FESS) for the management of nasosinus disease. A number of published studies demonstrated the clinical effectiveness of these techniques, and reported a successful outcome in more than 85%, with the overall rate in the region of 76-98% (Moses *et al.*, 1998). Progress was complimented by the development of new instrumentation of various designs, together with their modifications. Although the laser technology was also introduced into surgical practice at the same time, its use in FESS remained somewhat circumspect. In *Clinical Rhinology* published in 1990, Maran and Lund devoted

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just one paragraph to lasers in turbinate reduction. Laser usage is conspicuous by its absence in the index of the title *Endoscopic Sinus Surgery* authored by Levine and May in 1993. Mehta (1993) introduced the laser in their rhinology practice, and gradually expanded its use. In their *Atlas of Endoscopic Sinonasal Surgery* published in 1993, they state that they use the laser for all procedures in rhinology. In *Endoscopic sinus surgery*, Kaluskar (1997) reported 112 cases of ESS in which the KTP:532 laser was used for a range of pathological conditions with 'great success'. These included nasal polyposis, excision of concha bullosa, turbinoplasty, FESS revision, middle meatal antrostomy, and occasionally, vaporisation of the posterior end of the inferior turbinate ('Mulberry posterior end of the turbinate') and of the middle turbinates. Laser technology facilitates minimally invasive surgery, which aims at the removal of diseased tissue and the restoration of ventilation and drainage of the sinuses, with minimum surgical trauma and preservation of mucociliary function.

The use of laser offers certain distinct advantages and helps to minimise the complication rate, particularly in revision endoscopic sinus surgery (RESS). Chapter 20 provides a fuller description of laser interaction on the nasal tissues. Briefly, the laser energy can be transmitted via a flexible optical fibre, allowing its delivery to almost any area in the nose. Its thermal effect not only ablates the tissue, but also provides excellent intraoperative haemostasis for precise and safe surgery. Unlike conventional forceps which remove tissue in large amounts, the laser removes the tissue from the nasal fossa outwards, vaporising it layer by layer, thus maintaining full visual control. Finally, by varying the laser parameters, thermal penetration and the extent of tissue destruction remain under the constant control of the operator, something that is not possible with cold instrumentation.

However, the laser should be considered an additional tool, and not a replacement for conventional cold or powered instruments. It is not intended to be used for 'everything and anything'. Its casual and injudicious use is just as dangerous as cold-instrument surgery.

2. Review of the literature

Kautzky *et al.* (1992) described the use of the pulsed Ho:YAG laser during ESS in ten patients with recurrent inflammation of the paranasal sinuses. A 600-μm quartz optical fibre carried the laser energy to the operation site. The tissue interactions, examined under light microscopy, showed that the photoablative mechanism of the laser light resulted in only a minor thermal component in the target zone. Kautzky *et al.* further demonstrated that, compared to other lasers, the Ho:YAG laser produced no carbonisation zone. The area of tissue damage was significantly smaller (370520- μm), and wound healing was satisfactory. Shapshay *et al.* (1991) evaluated bone ablation, tissue coagulation and the haemostatic properties of the Ho:YAG laser. They performed *in vivo* and *in vitro* studies during ESS in a laboratory setting on beagle dogs, the heads of six human cadavers and of one calf. Ho:YAG laser energy resulted in controlled soft tissue and bone removal. There was also good intraoperative haemostasis. All sinuses were accessed adequately with the flexible optical fibre. Shapsay *et al.* concluded that the use of laser is warranted in order to increase the precision and safety of ESS.

Ikeda and Takasaka (1996) used the KTP:532 laser to perform ESS surgery on 80 patients suffering from chronic sinusitis and mucocoeles. They demonstrated excellent results, showing reduction of postoperative polyps and granulation tissue around enlarged maxillary sinus ostia. In addition, patients with chronic sinusitis showed improved healing of polypoid degeneration of the mucosa in the maxillary sinus. A 600-μm fibre delivered an average power of between 5 and 9 W. No complications were encountered in this series. The authors concluded that the KTP:532 laser is a promising tool in ESS. Leunig *et al*. (1999) reported similar findings in a prospective study of 85 patients at the one-year follow-up.

Metson (1996) used the Ho:YAG laser on one side and conventional cold instrumentation on the other during FESS in a prospective, randomised, controlled, single-blinded study of 32 patients. These patients were followed up for two years. Metson demonstrated that the mean intraoperative blood loss on the laser-treated side was 24.6 ml less than on the conventional side ($p < 0.001$). Postoperatively, there was increased mucosal oedema on the laser-treated side ($p < 0.01$), but there was less crusting. There was no difference in improvement in the symptoms of pain, congestion, or drainage between the two sides. Microscopic analysis of the tissues showed that the depth of tissue removal with the Ho:YAG laser was dependent upon the energy per pulse. The depth was 260 ± 8.2 µm at 0.5 J, 286 ± 9.4 µm at 1.0 J, and 341 ± 20.4 µm at 1.5 J, per pulse energy level. A zone of thermal necrosis extending up to 1 mm beyond the site of laser impact was consistent with the increased postoperative oedema observed on the laser-treated side. The study concluded that the laser offers very precise tissue interaction in terms of ablation, and much less bleeding than conventional methods.

3. Indications for laser functional endoscopic sinus surgery

The lack of clear indications is a reflection of the slow progress in the acquisition of this rather expensive technology. It is also due to the overriding concern regarding the potential damage it may cause to vital structures in the vicinity of the nose and paranasal sinuses. Nevertheless, the lasers offer some unique advantages described later in this chapter.

While the laser can be used to assist any particular operation, certain conditions render themselves well for laser ablation. The following examples illustrate its use in ESS:

3.1. Removal of polypi as a preliminary procedure to FESS

Polypoid mucosa or frank polypi covering the middle turbinate, uncinate process and bulla ethmoidales are vaporised efficiently, safely and quickly, without any of the 'tug and pull' invariably associated with cold instrumentation. More importantly, this preliminary procedure exposes the anatomical landmarks so that a definitive procedure can be undertaken with greater safety.

3.2. Manipulation of middle turbinate

Gross manipulation of the middle turbinate with cold instruments may result in a flabby turbinate, which may attach itself to the lateral wall of the nose. The laser allows bloodless removal of the bony lamella of the middle turbinates in turbinoplasty for concha bullosa and/or paradoxical turbinates with preservation of the mucosa, thus avoiding any possibility of a 'flabby turbinate'.

3.3. Solitary sphenoid or frontal sinus disease

In solitary sphenoid sinus disease, a fibre-transmitted laser can be transnasally directed into the sphenoethmoidal recess in order to coagulate vessels on the anterior wall of the sphenoid sinus. Sphenoidotomy is then an almost bloodless procedure. Similarly, frontal mucocoeles can be tackled by undertaking minimally invasive surgery with the laser.

3.4. Intraoperative haemostasis

Used in the defocused mode, the laser is very effective in controlling mucosal oozing during ESS. This mode is conveniently achieved by simply withdrawing the fibre slightly, so as to defocus the beam.

3.5. Revision endoscopic sinus surgery

Although the laser can be used for various primary FESS procedures, the author believes that its main advantage lies in its application to revision endoscopic sinus surgery (RESS), where the anatomy is distorted and covered with scar tissue. The laser allows ablation of the scar tissue, so that the landmarks are laid bare (Figs. 1 and 2). Application of lasers in RESS is described below, under a separate heading.

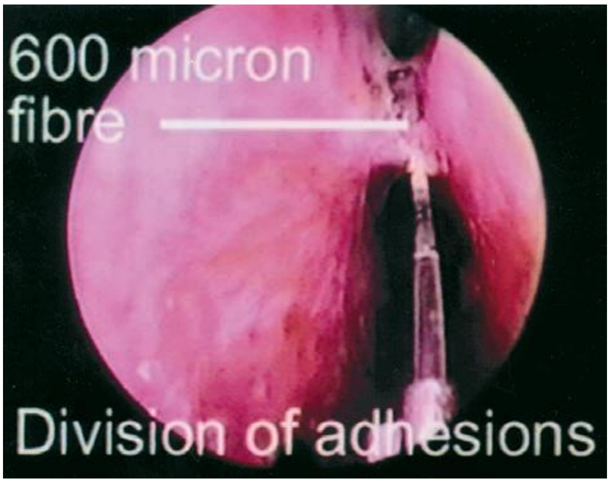

Fig. 1. Right nasal cavity: division of adhesions.

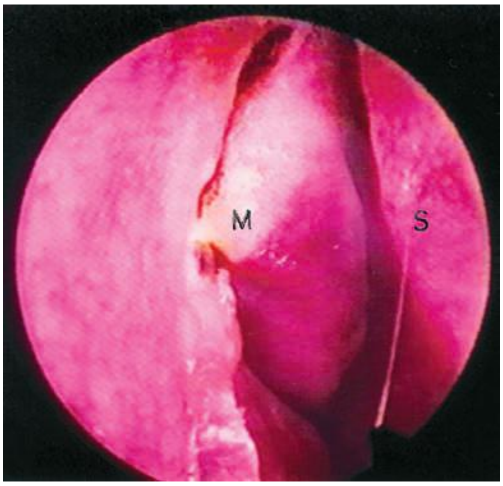

Fig. 2. Right nasal cavity: atraumatic and bloodless separation of an adherent middle turbinate from the lateral wall of the nose. (S = septum; M = middle turbinate)

4. Contraindications for laser functional endoscopic sinus surgery

In the presence of gross polyposis of the nasal cavities and paranasal sinuses, laser instrumentation alone will be very time-consuming. In such cases, the use of cold and power instruments is appropriate. Subsequently, lasers may be used to clear the disease from inaccessible areas. Any suspicion of orbital, facial, or intracranial extension of the disease process is also a contraindication for laser use (JH).

Apart from an extensive disease process, the most important contraindication is lack of adequate training in the usage of laser technology. The availability of laser wavelength also governs the application. As an example, the CO_2 laser is not truly fibre-transmissible, and its use in FESS is somewhat restrictive.

5. Preoperative evaluation (preparation)

There are no patient preparations unique to laser usage. As in conventional FESS, the patient's nose is prepared so as to achieve maximum vasoconstriction during the operation.

6. The author's (SK) experience of laser usage in functional endoscopic sinus surgery

Over a period of nine years, the present author has routinely used the KTP:532 laser (Laserscope, San Jose, CA) during ESS in more than 225 patients, including revision procedures. These procedures included excision of the uncinate process (Fig. 3), removal of bulla ethmoidales, and creation of middle meatal antrostomy (MMA). The procedures were almost bloodless and postoperative packing was rarely required. Experience showed that the use of the laser shortened the in-patient stay, produced much less oedema and crusting, and reduced postoperative morbidity.

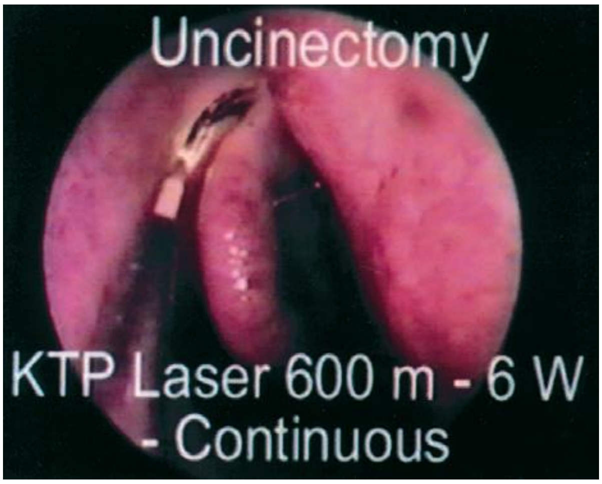

Fig. 3. A. Right nasal cavity showing uncinectomy.

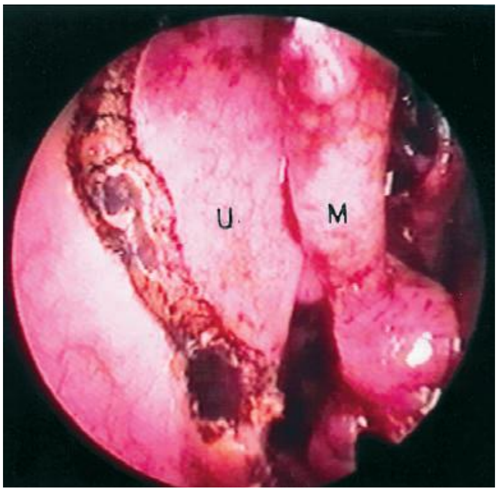

Fig. 3. B. Right nasal cavity with completed uncinectomy. Note the bloodless incision and identification of natural ostium of the maxillary sinus. (U = uncinate process; M = middle turbinate)

7. The KTP:532 laser

The KTP:532 laser emits in the visible range of the electromagnetic spectrum and, thus, unlike the CO_2, Nd:YAG or diode laser, it does not require a superimposed aiming beam. This ensures high surgical accuracy in the application of the laser energy to the tissues in the nasal cavity, especially when working in critical areas such as the lamina papyracea, frontal recess near the thin lateral lamella of the cribriform plate, and roof of the sphenoid sinus. Tissue penetration into the vasculature is not as extensive as with the Nd:YAG laser, and thus the KTP laser can be used safely near the orbit and the skull base.

The KTP wavelength is fibre transmissible. The Microstat® fibres are available in various core diameters. The author uses a 600-µm diameter fibre. This is a commonly used size for all ENT operations. An 800-µm fibre is too thick, less manoeuvrable, and has a large spot size.

7.1. Laser parameters for the KTP:532 wavelength

The following parameters relate to the KTP:532 laser, model 800 series. The rapid pace of technological advance means that newer models are being introduced all the time. It is therefore advisable that the reader should follow the manual relating to their model, and only use the following remarks as general guidelines. It is 'good practice' to assess the performance characteristics of a newly acquired wavelength on animal tissue, easily available from a butcher's shop, before using it in a clinical situation.

When deciding which power settings should be used, it is necessary to take into account the type and consistency of the tissue to be ablated. Different powers are required for vaporising polypi, thickened mucosa, or fibrous tissue of the anterior and posterior fontanelle. Another consideration would be the proximity of such delicate structures as the thin bone of the ethmoid cells, ground lamella, anterior wall of the sphenoid, and the thin 'eggshell' bone of the agar nasi cells. There should be minimum thermal damage to these structures. In the majority of patients, the author has found that the energy level of 6-8 W power, delivered in the continuous mode, and guided with a 600-µm spot size, is adequate. For nasal polypi, with a greater mass for ablation, a higher power of 10 or even 12 W is needed. These settings represent the author's experience with his own KTP:532 laser with a minimum calibration of 80% (usable power level at the fibre-tip end). The reader is urged to assess the safe but effective power levels of his/her own KTP, or indeed of any other laser, by striking non-vital tissue with different power settings.

7.2. Laser application technique

Although the following comments relate to the author's experience with the KTP:532 laser, they are applicable to any fibre transmissible laser. It is necessary to avoid aggressive application of the laser energy continuously to the tissue at any particular site. Ablation is carried out by swift and rapid excursions of the fibre tip over the tissue surface, so that irrandiance (total energy delivered to the given area of the tissue) is minimised. Following this technique, in the author's hands, no complications or thermal damage to the surrounding vital structures such as orbital tissues, optic nerve or the skull base, have been encountered (Kaluskar, 1997,1999a, b). Since the bleeding is minimal, surgical landmarks are not obscured. However, should the bleeding be excessive, it can usually be controlled by temporary packing with wet saline ribbon gauze.

In common with all truly fibre transmissible lasers, the energy of the KTP:532 can be controlled by simply withdrawing the fibre for coagulation, and advancing it for cutting and vaporisation of the mucosa of the nose and sinuses. Thus, the vascular mucosa may be initially coagulated by exposing it to the laser energy delivered from a distance of, say, 5 mm, and then advancing the laser to the near-contact position to cut the mucosa or to vaporise it bloodlessly. The vaporisation mode of the KTP:532 laser is particularly useful for vaporising any polypi obscuring such important landmarks as the middle turbinate and the uncinate process.

While working in the proximity of vital structures, it is appropriate that the fibre be withdrawn somewhat, and the energy reduced, so that the tissues are coagulated rather than vaporised. The coagulated tissue is then removed by suction, or wiped with ribbon gauze moistened with saline.

If charring is formed on the surface of the tissues, it is removed by suction or with wet ribbon gauze. This is important, as, lasing charred surface results in further secondary thermal damage to the surrounding vital structures.

8. Instrumentation

A specially designed hand-piece for delivery of the laser energy consists of a channel for the optical quartz fibre and suction channel, and a 4-mm diameter channel for the endoscope. The author uses a modified microstat with a suction channel in one hand and an endoscope with a camera in the other. It is necessary to attach a filter, specific for the KTP laser, to the endoscope in order to prevent exposure of radiation to the surgeon's eye. The assembly is completed with the attachment of a suitable CCD camera so that a monitor image can be used to undertake the operation. The use of a monitor has many advantages. It gives the surgeon an enlarged and biocular view, and also provides an excellent opportunity to demonstrate the operation to trainees and nurses. Archiving is carried out by means of a CD or a DVD writer.

9. Specific functional endoscopic sinus surgery procedures

The following paragraphs describe some common clinical applications of the KTP:532 laser in nasal pathology.

9.1. Nasal polyps

Small sessile nasal polyps are easily vaporised with the energy delivered in the near-contact mode. The advantage of using a laser for this simple procedure is that, due to the bloodless and layer-by-layer vaporisation, the underlying anatomical structures are clearly laid bare, exposing any further pathology. If large polyps are present, the laser energy can be applied interstitially by inserting the optical fibre and delivering the energy. This method results in shrinkage of the polyps, exposing the landmarks.

The KTP laser has also been used to vaporise the base of antrochoanal polyps following removal of the choanal part and the main antral part via middle meatal antrostomy, in order to minimise the incidence of recurrence.

9.2. Removal of bulla ethmoidales

It is important to note that quite often bulla extend upwards towards the skull base and, in some cases, even anteriorly up to the frontal recess. The residual disease usually remains in the upper part of the bulla. Using 6 W of KTP laser power, the bulla can be removed and the disease exteriorised.

9.3. Clearance of agger nasi cells

Agger nasi cells are the anterior-most ethmoidal cells of the ethmoid labyrinth (see Fig. 7). The anatomy of these cells is often variable and is made more complicated by adjoining structures, such as the upper extension of the uncinate process, bulla ethmoidales, and in some cases, ground lamella. Exenteration of these cells is technically rather difficult as it is usually necessary to use a 70° endoscope (Kuhn, 1996). The view through an angled endoscope is distorted and may lead to increased instrumentation trauma with forceps and suction. The procedure may be associated with bleeding due to injury to the anterior ethmoidal artery, with the risk of intracranial or orbital complications. In this situation, the laser offers the considerable advantage of an almost bloodless procedure. The laser is used with 6-W continuous energy in order to vaporise the oedematous and polypoid tissue with comparative ease, and may lead to a frontal recess. Inadequate management of these cells is one of the most common causes of residual disease.

9.4. The frontal recess

In order to understand surgery of the frontal recess, it is necessary to be thoroughly conversant with the anatomy of the agger nasi cells. These are variable cells, both in number and size, located very near the skull base in relation to the lateral lamella of the cribriform plate on the one side and the lamina papyracea on the other (Ohinishi, 1993). The opening of the frontal sinus ostium is usually medial in the majority of patients, near the lateral lamella of the cribriform plate. Before working in the frontal recess, it is important to identify the skull base posteriorly. Alternatively, the frontal recess should be followed by keeping the bulla intact ('the intact bulla technique for the frontal recess'). In addition, the anterior ethmoidal artery is also in close proximity and, if damaged, significant bleeding can occur with occasional intraorbital haemorrhage. Once again, thin 2- or even 1-mm CT scan cuts are necessary in order to understand the precise surgical anatomy of these cells, together with the upper attachment of the uncinate process and extension of the bulla ethmoidales.

Any instrumental trauma either with suction or forceps, or excessive lasing should be avoided in the area of the frontal recess. Stripping of the mucosa or destroying the mucosa with a laser in this area will inevitably result in scar tissue causing further obstruction to the frontal sinus drainage, with consequent frontal sinusitis (Stammberger, 1986).

9.5. Middle meatal antrostomy

Middle meatal antrostomy (MMA) is not a substitute for FESS. It is essentially an enlargement of the natural ostium and is only one part of FESS. An appropriate descriptive term for MMA should be infundibuloplasty, since it extereorises the stenotic areas of the ethmoid chambers (infundibulum) and restores normal physiological ventilation and drainage to the anterior group of sinuses along normal mucociliary pathways. Creation of a simple 'hole' in the fontanelle in the middle meatus under the middle turbinate is not an MMA. If the underlying ethmoidal disease is not tackled, a mere MMA results in continuing infection of the ethmoid, maxillary and frontal sinuses.

To create an MMA, the KTP:532 laser is set at 8W power, in the continuous mode. If the accessory ostium is present, it should be incorporated into the natural ostium by vaporising the fontanelle with the laser (Fig. 4). This step would prevent recirculation of the mucus or mucopus in the maxillary sinus. Should there be any difficulty in identifying the natural ostium in the revision case, then a combined approach MMA (CAMMA) procedure is recommended (Kaluskar, 1997). With this technique, a stab incision is made through the canine fossa. A trocar and canula are inserted into the maxillary sinus through the incision. The trocar is then withdrawn and an endoscope introduced. This enables the surgeon to see and monitor the instruments inserted through the nasal cavity, in order to identify the natural ostium and create an MMA in difficult cases, without danger to the orbital contents. Finally, a large antrostomy is neither necessary nor physiological. In fact, the author has seen cases in which patients with very large antrostomies suffer from frequent facial pains during inspiration, as the inspiratory air currents directly impinge on the maxillary sinus mucosa. The natural ostium of the maxillary sinus is normally protected from the inspiratory air currents by the uncinate process. It is also much more oblique in its position, and the surgeon, after removal of the disease in this area, should leave the structures as near normal as possible. The dogma 'remove as little as possible, but as much as necessary' is nowhere more true than in the creation of an MMA.

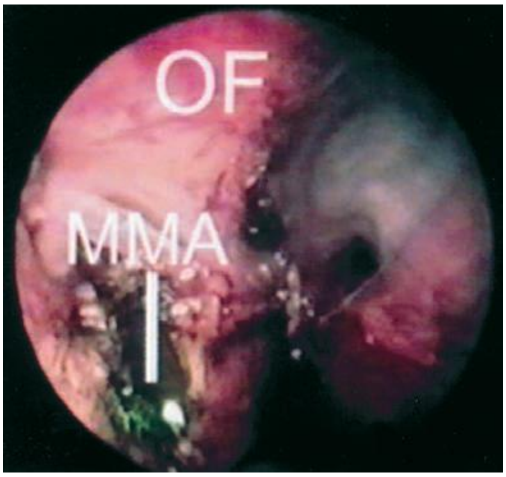

Fig. 4. Right nasal cavity showing MMA in a revision case with dehiscent lamina papyracea and exposed orbital fat (OF). Laser parameter: 0.6-mm spot, 6 W continuous.

9.6. Surgery on the posterior ethmoids and sphenoid sinus

Appreciation of the surgical anatomy of the ground lamella is the key to the removal of the cells of the posterior ethmoids prior to entering the sphenoid sinus. The ground lamella is a thin bony plate; it is the main attachment of the ethmo-turbinates to the lamina papyracea.

The ground lamella essentially extends in three directions, *i.e.*, anterior to posterior, inferior to superior, and medial to lateral. In many patients, the ground lamella also extends more anteriorly towards the frontal recess, thus causing an obstruction to the drainage of the frontal sinus. In surgery of this area, it is often the upper and anterior part of the ground lamella that is not adequately removed. The ground lamella must be entered more medially at the junction of the horizontal and vertical part (KTP laser set at 6-W continuous power) to remove the diseased posterior ethmoidal cells (Fig. 5). In some cases, there are polypi and/or thickened mucosa in this region. It is necessary to vaporise such tissue before entering

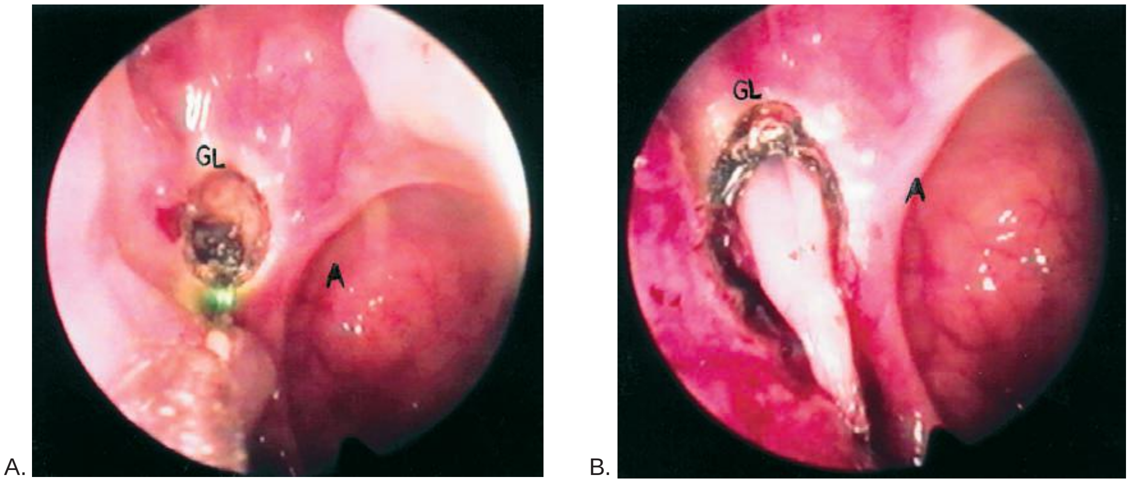

Fig. 5. FESS in left nasal cavity for posterior ethmoiditis. A. Left nasal cavity in a revision case showing laser ablation of the grond lamella. B. Pus evacuated from posterior ethmoids. (GL = grand lamella; A = antrum)

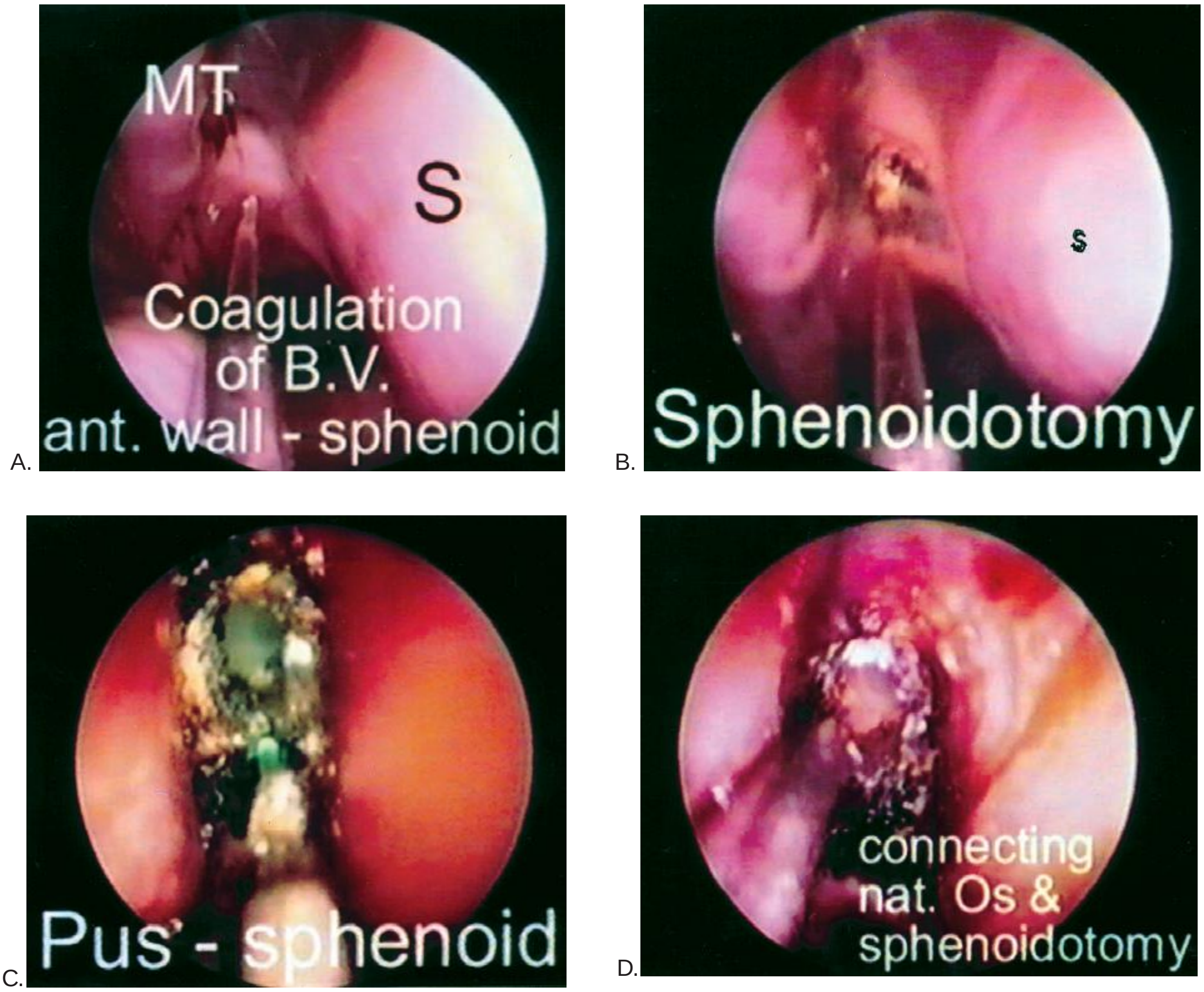
MT
S
Coagulation
of B.V.
ant. wall - sphenoid
A.
S
Sphenoidotomy
B.
Pus - sphenoid
C.
connecting
nat. Os &
sphenoidotomy
D.

Fig. 6. Right sphenoidotomy. A. Anterior wall of the right sphenoid showing coagulation mode of the laser energy prior to sphenoidotomy being performed. B. Right sphenoidotomy in progress – note complete absence of bleeding. C. Pus in the sphenoid. D. Right sphenoidotomy complete with removal of thin bone between natural ostium and sphenoidotomy. (S = septum; MT = middle turbinate)

the posterior ethmoid cells. It is important to study the anatomy of the posterior ethmoidal cells and the sphenoid on a CT scan before tackling the disease, since the vital structures such as the optic nerve and the internal carotid artery are at risk in the posterior ethmoids and sphenoid sinus, respectively. The anterior wall of the sphenoid is vaporised (KTP power 6 W), and the sinus is opened up to and including the natural ostium (Fig. 6). The three useful surgical landmarks for the sphenoid sinus are: the upper border of the posterior choana, posterior part of the nasal septum, and superior turbinate. Due to the higher incidence (23%) of carotid artery dehiscence in the lateral wall of the sphenoid, no instrumentation should be performed within the sphenoid sinus.

10. Revision endoscopic sinus surgery

Although the success rate of primary FESS, with either conventional or laser treatment, is high, in some 15-25% of cases (Moses *et al*., 1998), the improvement may be short-lived on account of inadequate surgery, or recurrence of disease. Further management is then advised, and is undertaken via an endoscopic approach during RESS. The operation for revision surgery demands considerable expertise. The site for the revision lacks the usual anatomical landmarks, and if present, they may be distorted due to scarring, oedema, congestion of the mucosa, and excessive bleeding. Consequently, the management of these rather demanding procedures has a greater risk of complications (Moses *et al*., 1998). The following general laser surgical techniques apply to the management of RESS.

With the correct technique and power setting, the excision of the uncinate process, removal of bulla ethmoidales (power 6 W continuous), and creation of MMA (power 8 W), can be performed almost bloodlessly, with minimal tissue trauma and crusting in the postoperative period (Fig. 7).

MMA is performed by vaporising either the anterior or the posterior fontanelle after identifying the natural ostium of the maxillary sinus. In the author's experience, the postoperative swelling and morbidity is less than with conventional instruments. Packing of the nasal cavity at the end of the procedure is not necessary in the vast majority of patients.

10.1. The common anatomical sites for residual or recurrent disease

While the residual or recurrent disease can affect almost any part of the nasal fossa, it is most frequently seen in some anatomical sites. These sites are difficult areas in FESS surgery and are intimately related to the vital structures, such as the orbit and skull base. Operating near the skull base requires an endoscope of either 30° or, preferably, 70°, which takes considerable time and expertise to handle properly, due to the distortion and foreshortening of the operative field. The difficult areas include the following sites:

- upper and lower third of the uncinate process
- upper segment of the bulla ethmoidales
- agger nasi cells
- anterior extension of the ground lamella
- posterior ethmoids and sphenoid sinuses
- frontal recess and frontal sinus

All cases for RESS are carefully assessed for any residual anatomical landmarks as well as for the nature and extent of the recurrent disease.

11. Postoperative care

The postoperative care following laser FESS is no different from that of conventional methods. The author's preferred protocol is to instruct the patient to use an alkaline nasal douche followed by a steroid nasal spray to be used for the first four to six weeks, by which time the ethmoid cavity and antrostomies are well epithelialised. The overall postoperative mucosal oedema is less with KTP laser compared to conventional surgery.

12. Outcome measures

There is no agreed method of measuring the outcome of FESS with conventional techniques or with the use of the laser. The reported results of FESS are basically subjective and are similar for both conventional and laser techniques.

13. Benefit and risks issue

Patient-perceived benefits are, less postoperative swelling and no packing. Morbidity is therefore much

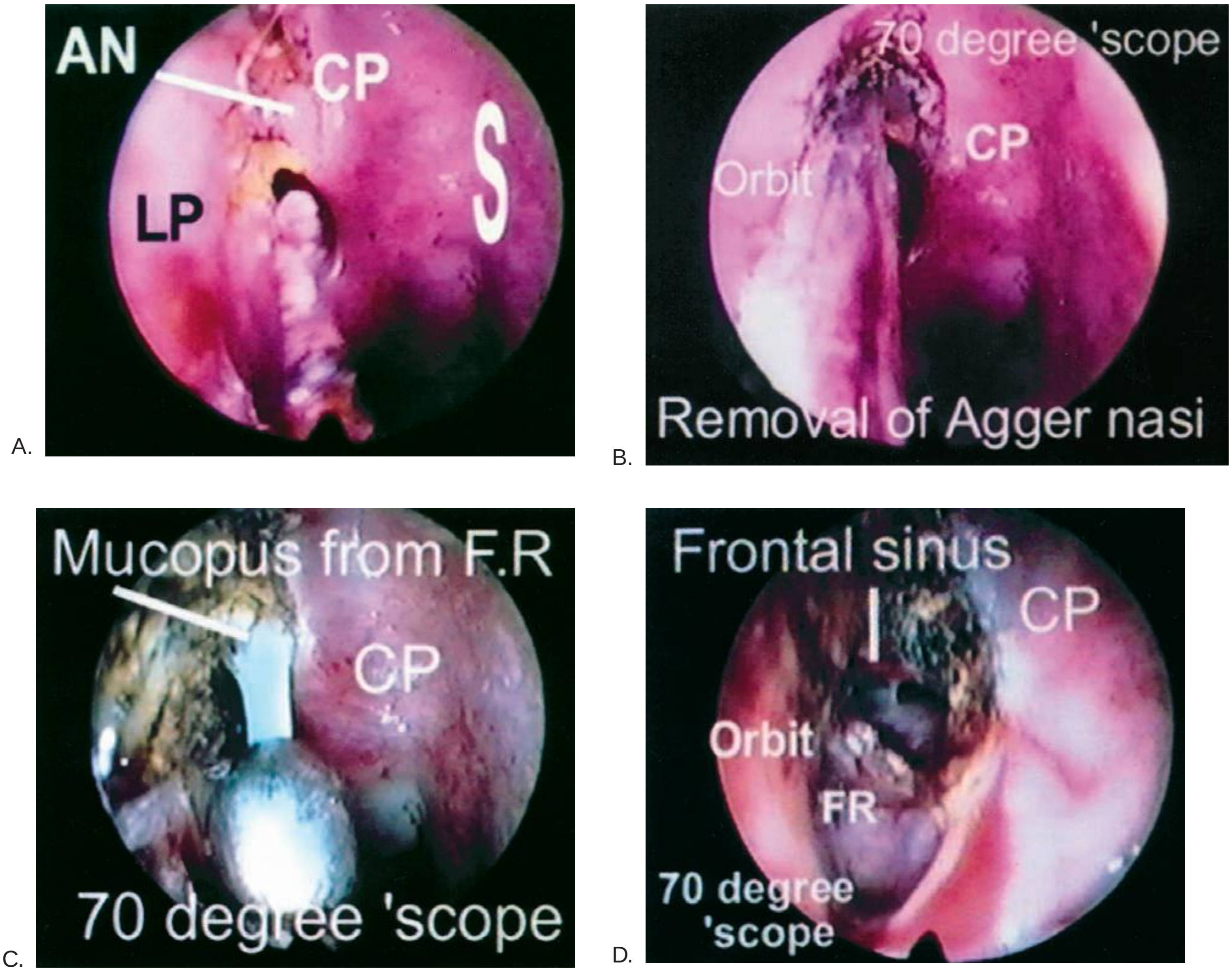

Fig. 7. FESS of right nasal cavity in a revision case. A. Laser ablation of 'egg shell' of the agger nasi cells. Note absence of middle turbinate. View with 4-mm 70° endoscope. B. Ablation in progress towards frontal recess. C. Pus draining from right frontal recess. D. Complete exposure of the frontal recess and sinus as viewed with 4-mm 70° endoscope. (AN = agger nasi; CP = cribiform plate; FR = frontal recess; LP = lamina paperacea; S = septum)

less. From the surgeon's point of view, the main reason for using a laser in FESS is for the precise surgical control, minimal tissue trauma, and less bleeding. These factors hopefully lead to a better surgical outcome.

RESS presents its own particular difficulties, due to the various factors discussed above. The laser provides a safe alternative for RESS.

A description of the risks of FESS is outside the scope of this work. Risks secondary to the use of lasers in rhinology have been described in Chapter 20. Suffice it to say, that these risks are completely avoidable by taking appropriate precautions. Risks to the patient arise from the following:

13.1. Aggressive continuous laser application

Risks associated with to the use of lasers in FESS are usually due to aggressive lasing of the tissues and damaging the underlying mucoperiosteum. This can result in the formation of sequestrum, chronic osteitis, granulation formation, and localised infection in the operated cavity. Excessive lasing of the mucous membrane with resultant thick charring, will also lead to crust formation, in its turn leading to nasal obstruction and possible infection in the cavity if the postoperative care is not adequate.

13.2. Adhesions

Scar tissue formation is inevitable after any type of surgery. In the nasal cavity, due to crowding of the structures and the close apposition of raw surfaces, adhesions are not uncommon. Adhesions interfere with the physiological function of mucociliary clearance and cause obstruction to breathing. Various methods have been used to minimise their occurrence, and these include packing, inserting spacers, suturing the middle turbinate to the septum, etc. The author's preferred method is to remove a small (about 1 cm) wedge of the anterior part of the middle turbinate with the KTP laser (power at 8-10 W in the continuous mode). This not only prevents lateralization of the turbinate, but also gives excellent access to the ethmoid cavity for care in the post-operative period (Kaluskar, 1998). The author firmly believes that an atraumatic technique in manipulating the mucous membrane and diligent post-operative care of the ethmoid cavity is all that is needed to prevent or to minimise postoperative adhesions.

13.3. Chronic osteitis

Aggressive lasing of the mucous membrane will result in destruction of the underlying mucoperiosteum, and should be avoided. It can also lead to chronic osteitis and formation of granulations with recurrent infection and excessive crust formation in the nasal cavity.

14. Conclusions

At the time of writing, the application of laser technology for FESS represents a small proportion of the overall laser usage in otolaryngology. Nevertheless, the use is increasing slowly but surely, as more and more surgeons are undertaking ESS. A comprehensive knowledge of the complex and variable surgical anatomy of the nose and sinuses is of paramount importance. The surgeon should be able to read and interpret CT scans in relation to the patient's symptoms and nasal endoscopy findings (Kaluskar, 1997). The importance of cadaver dissection before undertaking FESS surgery cannot be overemphasized. Likewise, it must be remembered that the laser is a refined tool, with specific advantages, as well as unwanted effects. A thorough understanding of the biophysics of the laser wavelength used is necessary in order to achieve optimum results, and, more importantly, avoid laser-related complications. As elsewhere in medicine, prevention is better than cure!

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Part B

J.U.G. Hopf, M. Hopf and H. Scherer

15. Surgical technique for functional endoscopic endonasal laser surgery

Functional endoscopically controlled endonasal and transnasal laser surgery (FEELS) allows the outpatient management under local anaesthetic of a large variety of common nasal disorders. Such a setup is associated with reduced patient morbidity and costs. The core knowledge for endonasal laser surgery and the local anaesthetic requirements for FEELS are fully covered in Chapter 20. Over the past several years, as technology developed, the authors' department was able to acquire newer laser wavelengths. The authors of Part B were thus able to obtain experience in a variety of wavelengths in the endonasal applications presented in this chapter. The KTP laser has already been covered extensively in Part A, and will only be mentioned in passing.

16. Nasal polypi

Polypi (Fig. 8) can be removed in two ways. When landmarks are relatively unobstructed, instant vaporisation and debulking is carried out with a high power level in the chopped mode. The laser beam is used in the contact position. The fibre is gently placed on the surface of the polyp. Once the laser has been activated, it is possible to observe the tissue shrinking towards the laser fibre tip.

However, in case of massive polyposis (Fig. 9), initial clearance is obtained by coagulating the base of the polyp with low power settings in the continuous mode. The devitalised tissue necroses so that the patient sneezes it out, or it can be removed bloodlessly during a review examination. The procedure is repeated until the landmarks are visible. Any residual disease is then removed using the laser for vaporisation.

In some cases of chronic rhinosinusitis, it is not uncommon to find that the middle turbinate is polypoid as well, and is obstructing ventilation of the infundibulum. Reduction can easily be achieved with laser vaporisation. This procedure allows access up to the posterior end of the inferior and middle turbinates, and any isolated pathology can be dealt with by advancing the fibre. Various lasers and their parameters for the management of nasal polypi are as follows:

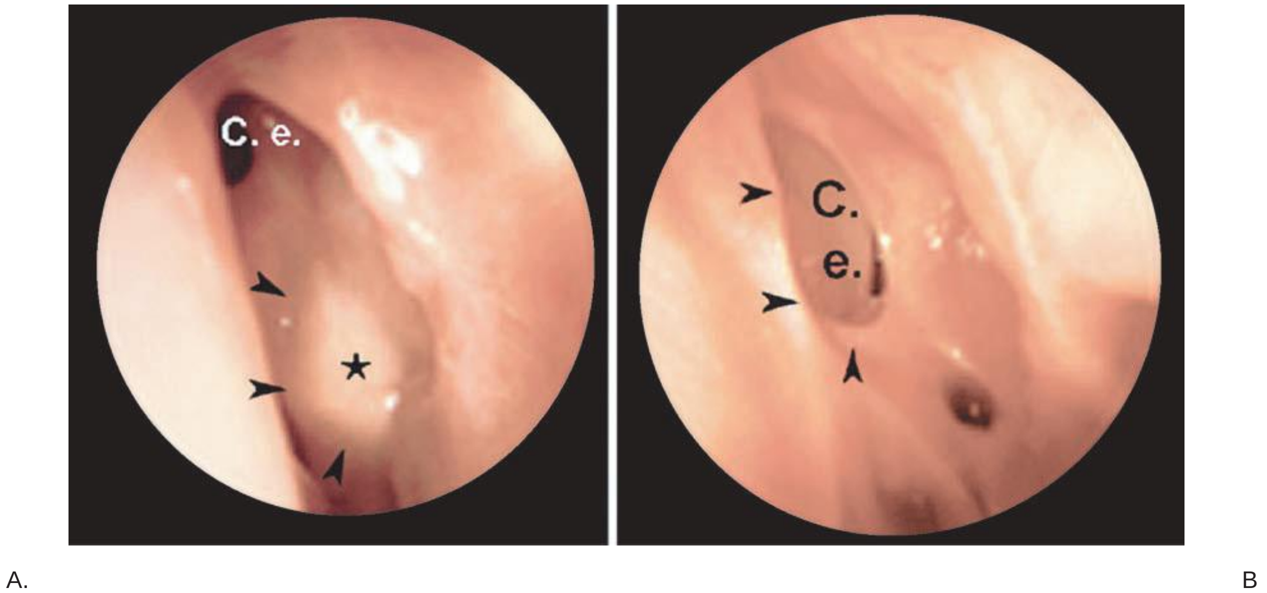


Fig. 8. Endoscopic laser removal of hyperplastic mucosa and polyp. A: Preoperative photograph of a patient with ethmoid cells (C.e.) obstructed by hyperplastic mucosa and polyps. B: Wide open access to the ethmoidal cells, no hyperplastic mucosa two months after laser surgery.

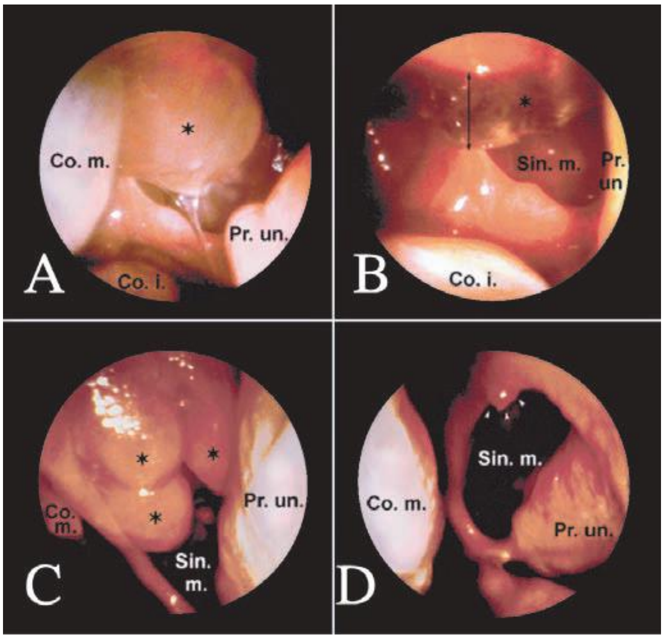


Fig. 9. Endoscopic laser removal of gross nasal polyposis. A: Polypi in the nose and sinuses, obstruction of the left maxillary ostium by polypoid mucosa. B: A view after laser treatment with 3 W continuous mode. Zone of irreversible damage is clearly visible (arrow). C: Obstruction of the supraturbinal maxillary ostium by polyps in the maxillary sinus. D: Supraturbinal ostium after endoscopic laser surgery with vaporisation technique. Arrows indicate the wound margin immediately after polyp resection. (Co.m = middle turbinate; Co.i = inferior turbinate; Pr.un = uncinate process; Sin.m = maxillary osteum)

16.1. Nd:YAG laser

For vaporisation, the Nd:YAG laser is used in the contact chopped mode, with a power setting of 35–40 W and an exposure time of 0.1 or 0.2 seconds.

For coagulation, the Nd:YAG laser is used in the contact continuous mode, with the power setting of 2-8 W.

For interstitial coagulation, the Nd:YAG laser is set at 2-8 W in the continuous mode. The fibre is carefully inserted into the polyp, the laser activated, and the tip gently advanced. The advantage of interstitial application lies in the fact that a large bulk of the polyp acts as a sleeve and can be coagulated without endangering the surrounding tissue. The nasal airway is restored progressively without the risk of haemorrhage.

16.2. 940-nm diode laser

The diode laser allows a very gentle approach to sensitive areas. In the chopped mode with extremely short exposure times and long pauses to prevent heat accumulation in the tissue, the 940-nm diode laser can be used for very precise work with only a minimal coagulation zone. The diode laser is used at lower power settings since, compared to the Nd:YAG, its penetration is shallower and the temperature gradient steeper. As a result, patients rarely complain of pain from the heating of tissues.

16.3. Argon–KTP laser

The argon ion and KTP lasers are useful due to their comparatively shallow depth of penetration. These lasers have been used to ablate tissue in the immediate vicinity of the skull base and olfactory epithelium.

16.4. Surgical outcome

Since polypi develop as a result of intrinsic mucosal disease, endoscopic laser surgery does not alter the course of the disease. However, the introduction of laser technology has resulted in rapid outpatient treatment for debulking (Fig. 10). If further polypi are seen during a review examination, the serial reduction of polypi can be undertaken without much discomfort for the patient. Neither admission nor nasal packing will be necessary.

In the authors' experience, in recurrent polypi with impaired nasal breathing, sufficient ventilation was restored after an average of three sessions of laser therapy scheduled at intervals of four to six weeks. In many cases, the sense of smell was also restored due to the precise, bloodless ablation of polypi obstructing the olfactory cleft at a low laser power and short pulse setting under videoendoscopic control. There were no cases of olfactory dysfunction due to laser surgery.

16.5. Postoperative management

Occasionally, excessive secretion, oedema, and crust formation may continue. It is imperative that topical steroid treatment be continued, since this not only reduces postoperative discomfort, but also prepares the patient for subsequent repeat procedures by reducing oedema.

Children (>8 years of age) with cystic fibrosis and recurrent polyposis were successfully treated with the laser. Maintaining nasal patency and improving ventilation and drainage reduced the incidence of infection. Due to the usually poor cardiovascular sta-

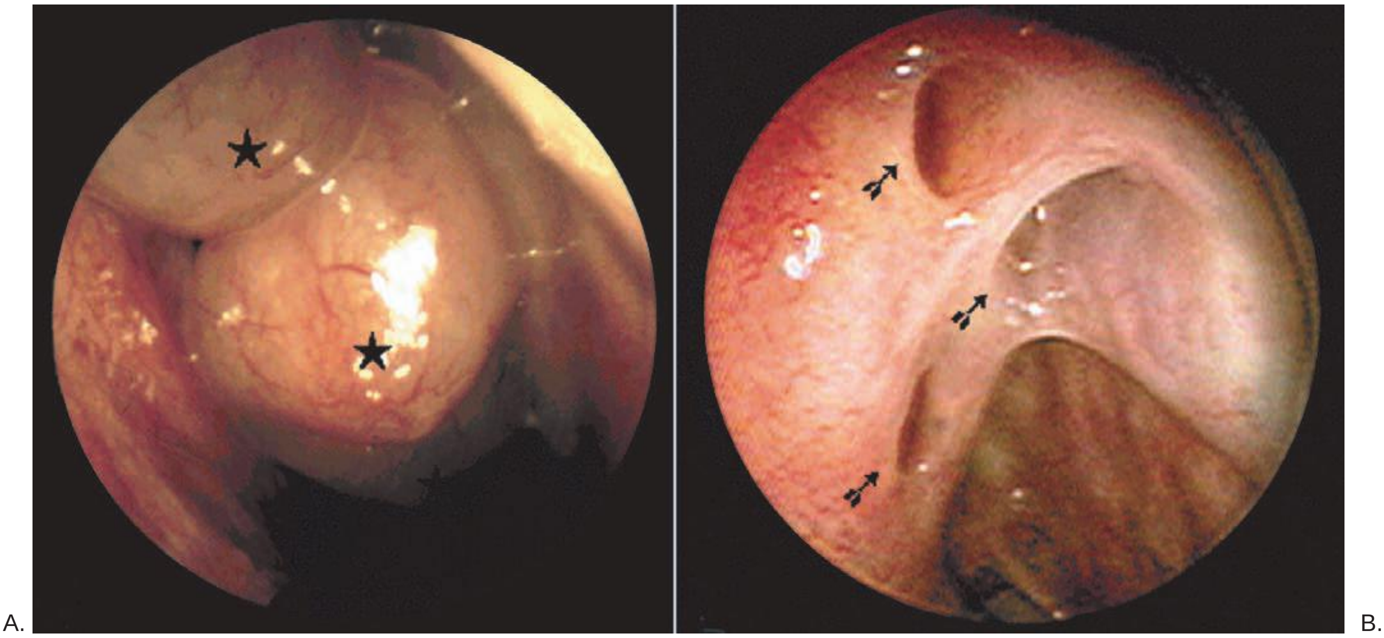


Fig. 10. A: Recurrent polyposis in the middle meatus, right side, prior to diode laser surgery. B: Disease-free ethmoidal cell system after successful FEELS procedure.

tus of these patients, it was essential to administer general anaesthesia in some cases. Many of these young patients had previously undergone one or more sinus operations.

16.6. Benefit and risk issue

It is, of course, necessary to exercise particular care in patients with recurrent polyposis. Removal of the orbital lamina in a previous FESS may have caused local soft tissue prolapse and have included some orbital material, which may rest directly under the polyp. This issue can be resolved with a coronal CT scan prior to commencing laser therapy (Fig. 11).

The distance to the anterior cranial fossa is small in patients previously subjected to complete ethmoidectomy. In these circumstances, the selection of high power settings in the continuous mode may, at least in theory, lead to the coagulation of intracranial structures. In this region, it is appropriate to apply the laser in the chopped mode, with short exposure times and long pauses between pulses. Secondary bleeding is extremely uncommon following laser usage in endonasal surgery. Necrosis of the bone is also uncommon, and heals without any long-term problems of sequestration.

There is a risk of iatrogenic orbital penetration with the ensuing possibility of injuring the external eye muscles and nerve structures, particularly in revision cases. Structures of the anterior cranial fossa may also be at risk, especially after previous conventional surgery, or due to rarefying osteitis of the frontal base. However, our experience shows that this risk is only theoretical if the laser is used competently. Both the intended and potential side-effects depend not only on the optical properties of the target tissue, but also, and more importantly, on the beam parameters. These include the power and pulse energy setting, total energy applied, and the application mode (*i.e.*, the chopped versus the continuous wave mode). Although such risks are intrinsic for all laser systems, they are probably more pronounced for pulsed lasers and not so common for continuous-emitting lasers such as the diode and Nd:YAG. It has also been our experience that the endo-orbital and endocranial bone particle spread described by Ossoff can only occur in pulsed lasers. Ossoff recommended that Ho:YAG lasers should only be used for pathology related to the septum and inferior turbinate.

Zhang (1993) reported that there is a risk of dural injury with CSF leakage. He argues that prolonged irradiation of small areas of tissue in the vicinity of the skull base in the continuous wave mode might predispose to CSF leakage due to the intracranial spread of thermal damage. Therefore, it is necessary to emphasize that the right choice of laser parameters is the key to reduce this risk.

17. Inferior turbinate hypertrophy

Laser management of enlarged inferior turbinates is covered in detail in Chapter 22. Working under endoscopic vision, it is important to create a white coagulation zone ('blanching') in the turbinate mucosa near the fibre tip. In this way, the procedure can be performed almost bloodlessly with either the Nd:YAG or the diode laser. Any bleeding that does occur is usually due to either an inadequate exposure time of the laser energy on the tissue or to mucosal tear due to inadvertent movement of the laser instrumentation in the nasal cavity. This can usually be controlled by continuing the exposure, or, in very rare cases, by another cycle of laser exposure by temporary packing using naphazoline-soaked cotton swabs.

Usually, a combination of instant vaporisation and coagulation results in the immediate improvement of nasal breathing. A good layer of coagulation seals off the vessels and also produces cicatrisation so that the nasal airway improves even further when the mucosal healing is complete. If the nasal airway is very crowded, the procedure is initiated in an anterior location, and advanced posteriorly as the tissues are vaporised and shrunk.

18 Laser-assisted surgical management of chronic rhinosinusitis

Chronic rhinosinusitis may result from hypertrophy of the soft tissues on the lateral aspect of the middle turbinate. Laser-assisted surgical management of chronic rhinosinusitis entails excision of the hyperplastic soft tissue in order to enlarge the transverse diameter of the middle meatus and facilitate ventilation of the maxillo-ethmoido-frontal compartment (Fig. 12). This procedure is also applicable to patients with recurrent symptoms following previous sinus surgery. For further reading, see Chapter 25.

19. Laser surgery of concha bullosa

The presence of a uni- or bilateral concha bullosa is another contributing factor to chronic rhinosinusitis, resulting in severe narrowing of the middle meatus and infundibulum (Fig. 13). Management involves not only the excision of soft tissues, but also complete surgical resection of the lateral portion of the bullous concha. Cold-instrument intervention here may well destabilise the remaining medial middle portion. Inadvertent fractures due to mechanical trauma may loosen the delicate bony insertion at the base. In contrast, the only mechanical aspect of laser management is the gentle contact with the tip of the laser fibre. The remainder of the procedure is undertaken by vaporising thermal energy without any tugging or pulling.

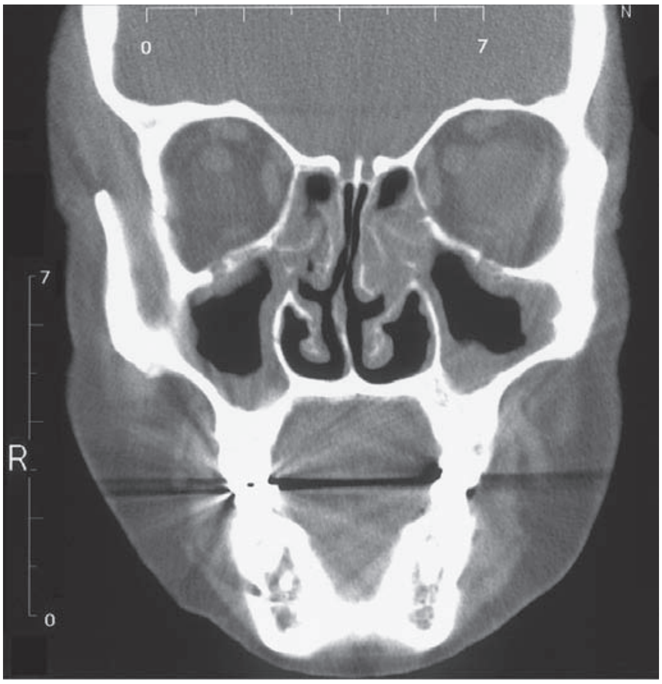


Fig. 11. CT scan in a patient with chronic rhinosinusitis due to recurrent polypi operated six times previously with conventional method. The scan shows an ideal candidate for a FEELS procedure.

19.1. 940-nm diode laser

The combination of the endoscopic laser rhinoscope sheath (Karl Storz, Tuttlingen, Germany) and the 940-nm diode laser (Dornier) is ideal for performing all kinds of procedures in FEELS, particularly for very narrow target areas such as the middle meatus (Fig. 14). By using the 940-nm diode laser with an extremely short pulse mode, the thermal damage to the bone is limited, resulting in satisfactory wound healing (Fig. 15).

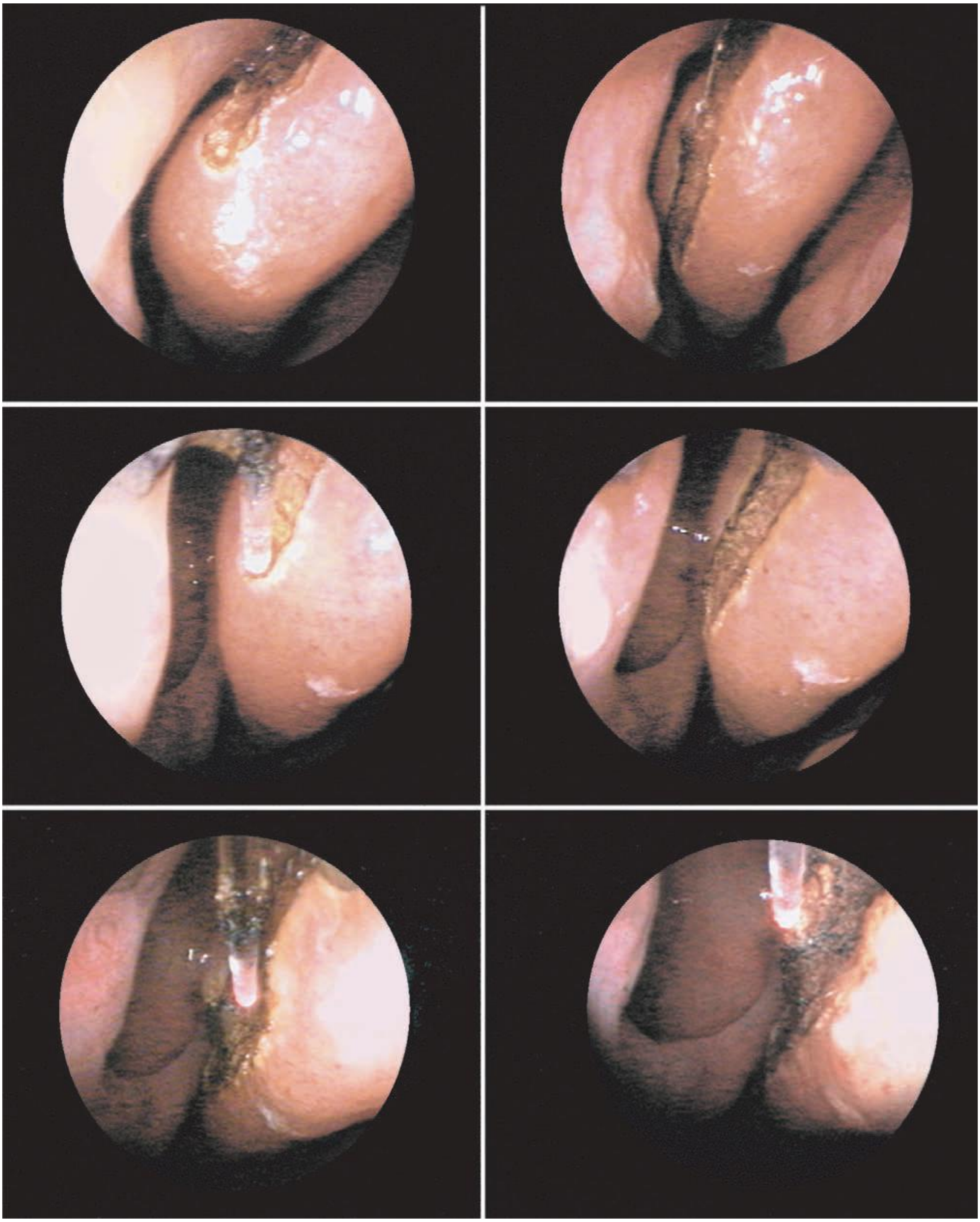


Fig. 12. Removal of hyperplastic soft tissue in the middle meatus. A slit-like middle meatus may result in chronic recurrent rhinosinusitis. Vaporisation of hyperplastic mucosa widens the middle meatus and improves ventilation of paranasal sinuses.

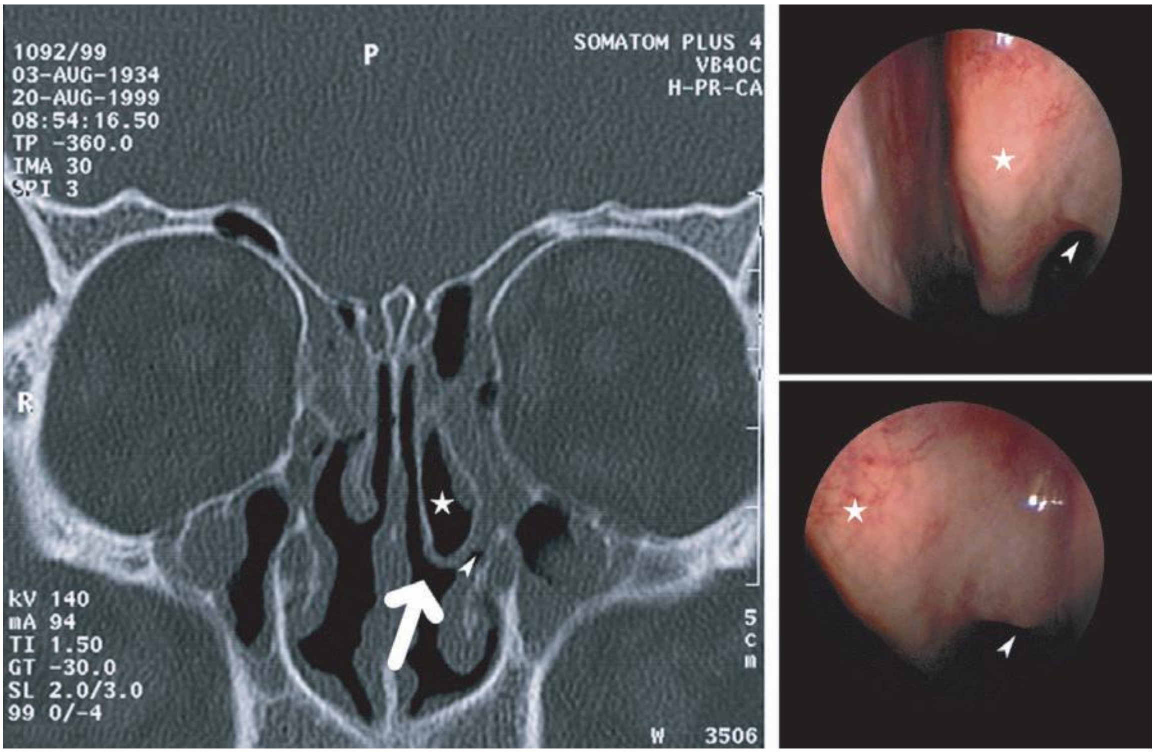


Fig. 13. Patient with recurrent sinusitis – concha bullosa media, left nasal cavity. The arrow represents the direction of the endoscopic view to the infundibulum and the obstructed middle meatus.

19.2. 810-nm diode laser

The 810-nm diode laser is also suitable for this type of procedure, although, with a maximum output power of 20 W, prolonged periods of exposure are required to vaporise the bone. This may lead to wider-spread thermal damage to the bone in some cases, and result in slightly more delayed healing.

19.3. Nd:YAG laser

Adequate partial resection of a medial bullous concha can also be achieved with the Nd:YAG laser. However, even when used in the contact position with precarbonisation, the scatter from the Nd:YAG causes widespread bony thermal damage, since it is poorly absorbed by the bone in the target tissue. The wound remains covered with slough for several weeks before healing is complete. Nevertheless, as with other laser systems, osteonecrosis is rarely seen, provided that the Nd:YAG laser is correctly used in order to minimise the thermal damage due to scatter.

19.4. Postoperative care

The patient is given a follow-up appointment for the removal of debris and crust by suction. The frequency of cleansing is determined individually as the healing progresses. It can be reduced by patients rinsing their nasal cavities. Nasal douche is advised. In contrast, vasoconstrictors or steroids should be avoided during the initial wound-healing phase.

Certain areas need particular care when using the laser. Areas that are involved in mucociliary clearance and lymphatic drainage should be spared. Thus, care must be taken not to coagulate the mucosal and submucosal tissue in the entire periphery of the ostium or neo-ostium.

The use of a flexible, steerable fibrescope allows the surgeon to gain access to hidden pathological structures in patients with a constricted nasal cavity and narrow middle meatus. Miniaturised telescopes and micro-endoscopes can also be used for this purpose.

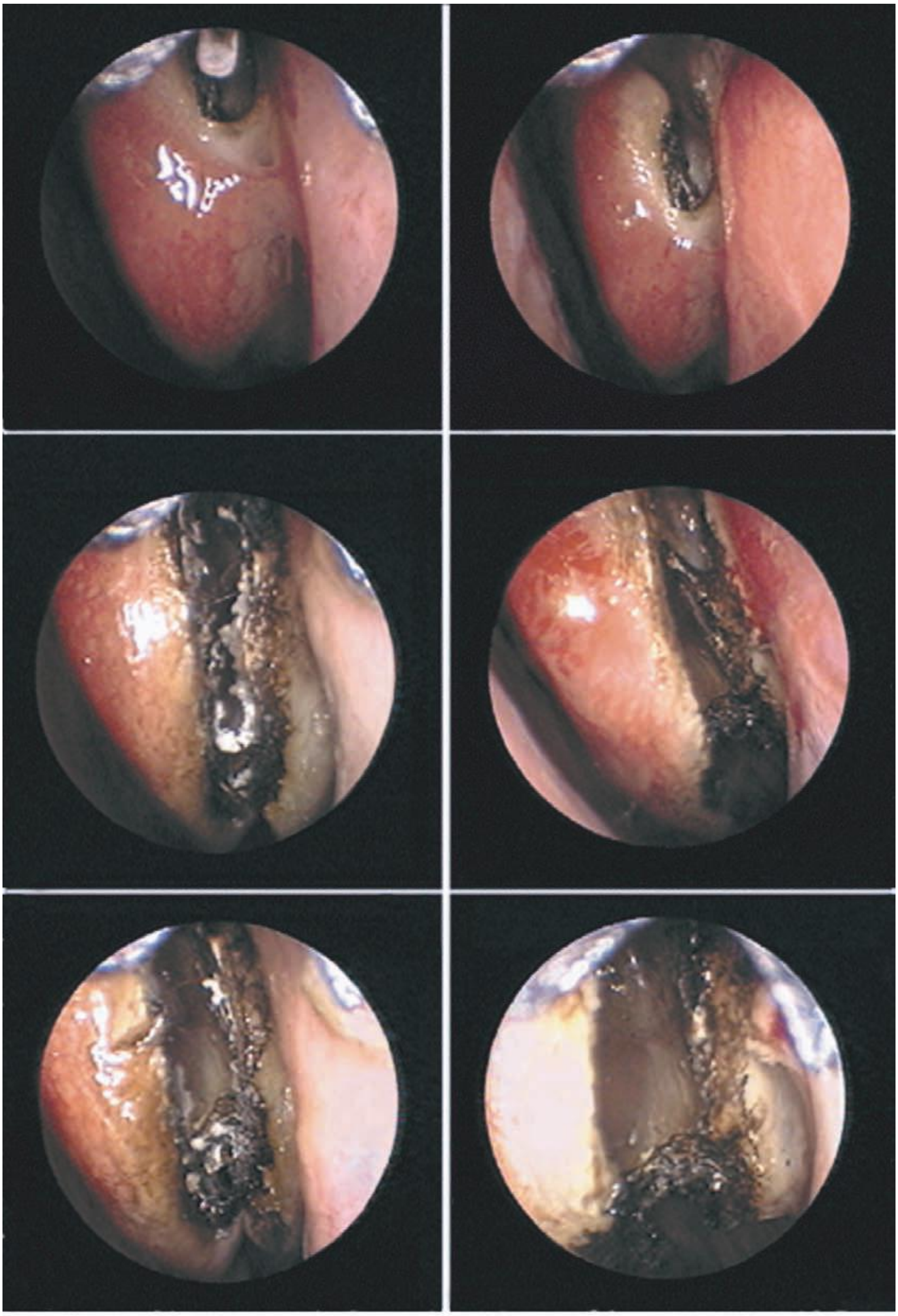


Fig. 14. With the short pulsed diode laser Medilas D (940 nm - DORNIER Company, Germany) the lateral bony lamella of a concha bullosa media can be vaporised and resected with only minimal coagulation of the surrounding tissue.

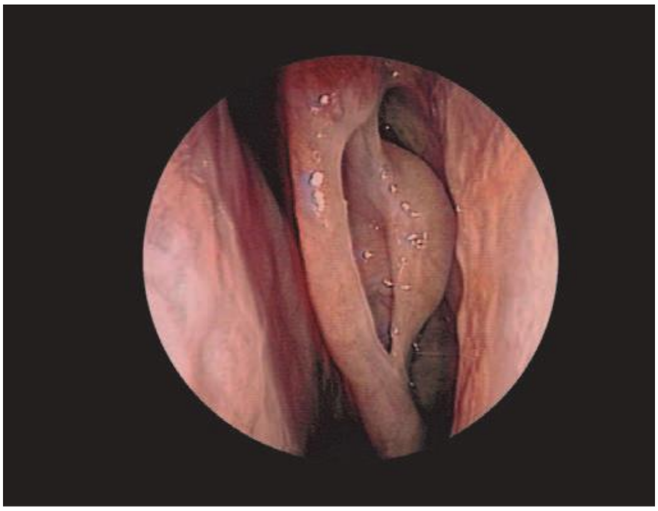


Fig. 15. Endoscopic view six months after diode laser-assisted resection of the lateral lamella shows open access to the anterior ethmoid as well as to the middle meatus.

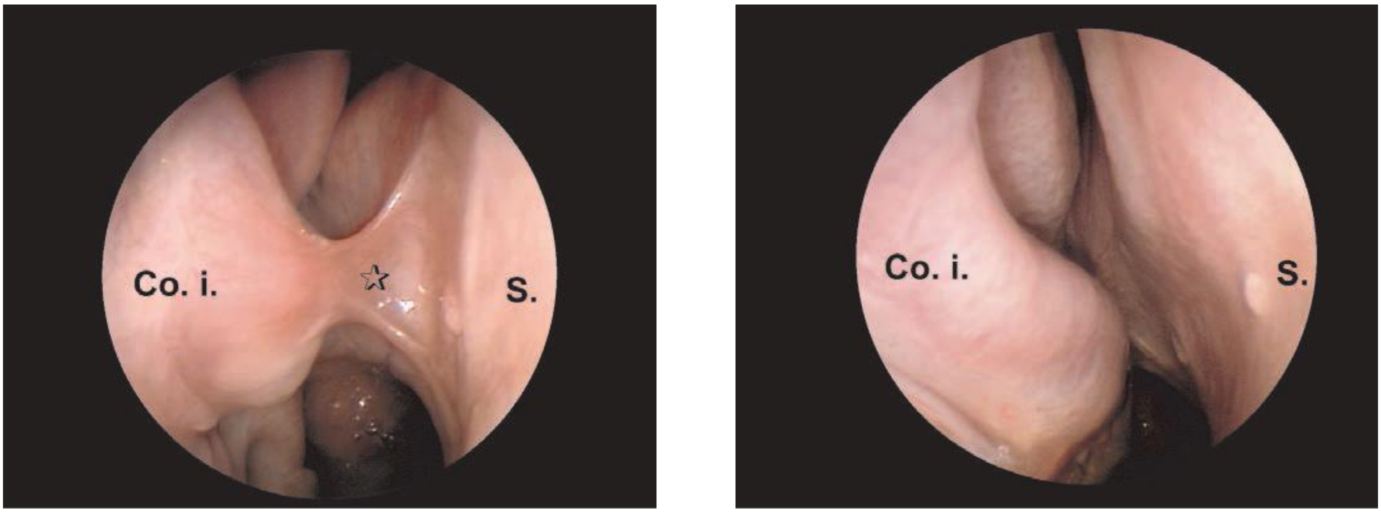
20. Synechiae, cicatricial stenosis and granulation

Synechiae (Fig. 16), excessive scarring, stenosis, and granulation tissue may form in the lower and middle meatus following conventional cold surgery, and result in chronic sinusitis and nasal breathing disorders. For this purpose, a high power (3560- W), fibre-guided, diode laser (wavelength: 940 nm) in the pulse mode is used. Nd:YAG, argon, and CO_2 lasers have also been used for this purpose. It is recommended that the synechiae are completely vaporised and that the adjacent tissues from which the synechiae originate are then coagulated, in order to create a wide space and to prevent recurrence. The laser makes the use of packing or spacers completely unnecessary, and the recurrence rate has been consistently low at less than 5%.

21. Septal spurs and septal crests

Small to moderate cartilaginous or partially bony septal crests and spurs can be excised with the diode laser in the pulsed mode at high laser power and short exposure intervals (35–50 W, 0.060.1- seconds), and a long interval between pulses (Figs. 17 and 18). However, it is important to limit the excision to one side of the septum only, in order to avoid perforation. The technique of septoplasty is described in detail in Chapter 53 on snoring. The CO_2 laser can be also be effectively used for septoplasty.

Laser septoplasty is limited to those cases in which the spur is unilateral and the opposite side straight. Spurs in the middle or lower nasal fossa touching the turbinate are ideal for laser septoplasty. All other cases of septal deviation should be managed by conventional instrumentation. It is useful to transilluminate the spur by placing the endoscope in the opposite nostril. This gives some indication of the thickness, and also warns the operator of a previously unsuccessful septoplasty, where the illumination is much brighter.A coronal CT scan, assessed preopera-



A.

B.

Fig. 16. Laser excision of synechiae. A. Endoscopic view of the posterior third of the right nasal cavity showing synechiae between inferior turbinate (Co.i.) and septum (S.). B. Endoscopic view four weeks after laser-assisted vaporisation of the synechiae. Normal mucosa at the septum and the inferior turbinate.

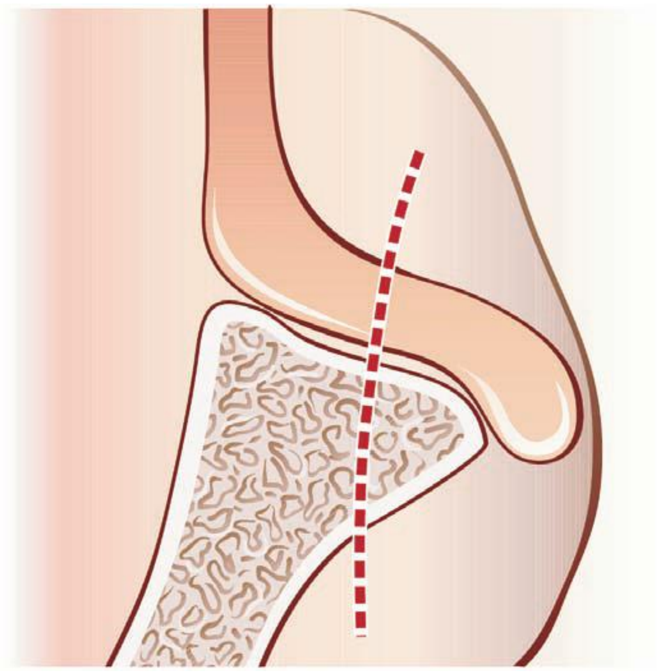


Fig. 17. Diagram showing the ideal case for the laser resection of a septal spur/crest.

tively, is much useful in demonstrating the thickness of the structures of the septum.

22. Mucocoeles and cysts

Nearly bloodless vaporisation and marsupalisation of mucocoeles (Figs. 19 and 20) can be undertaken by the laser resecting the wall. Similarly, cysts in the maxillary sinus can be excised under fibreoptic control by taking advantage of the enlarged ostia.

23. Granulomas and large haemangiomas

Laser energy is very useful in the treatment of non-specific (or specific) granuloma or haemangioma, and the whole lesion can usually be treated in one session (Figs. 21 and 22). The lesion blanches by careful coagulation, with marked delineation from the adjacent tissue.

24. Discussion

The laser is not a substitute for conventional functional endoscopic sinus surgery. Rather, it is a useful surgical instrument, which, like all other surgi-

A.

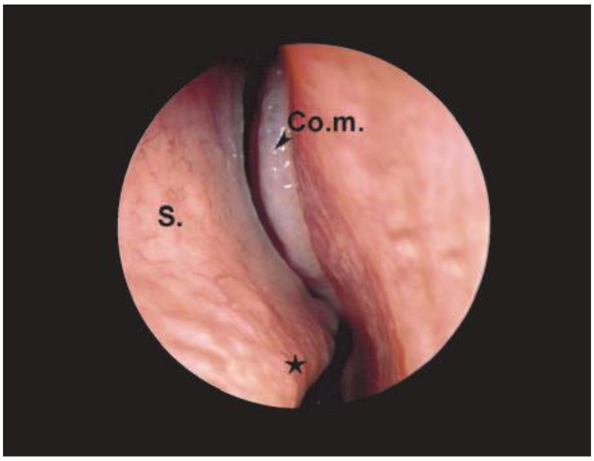


Fig. 18. Laser vaporisation of an obstructing septal crust. A. A 29-year-old patient with impaired nasal breathing. Endoscopic view of the left nasal cavity. The septum is in the mid-line, but a large septal crest is obstructing the left airway. The inferior turbinate is normal. The crest extends up to the posterior third of the nasal cavity. (S = septum; Co. m = middle turbinate)

B.

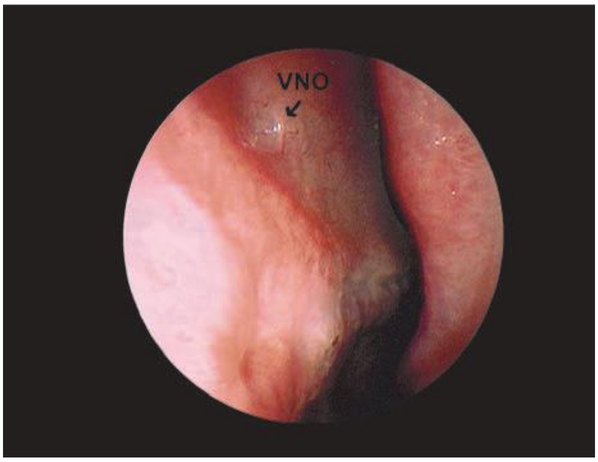


Fig. 18. B. Six weeks postoperative. The healing is complete with re-epithelialisation of organum vomeronasale (VNO).

C.

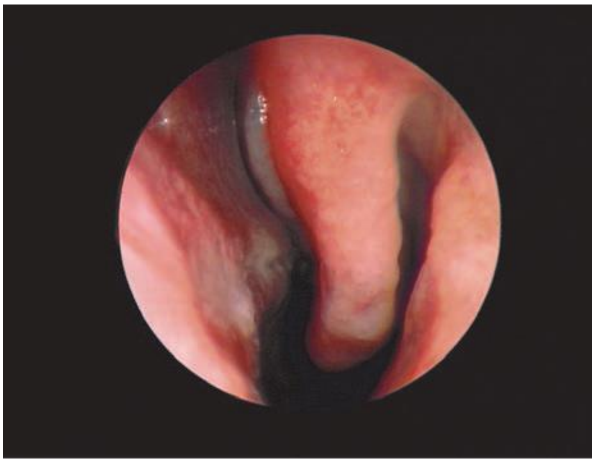


Fig. 18. C. Twelve weeks postoperative. Patent nasal airway with restoration of nasal breathing.

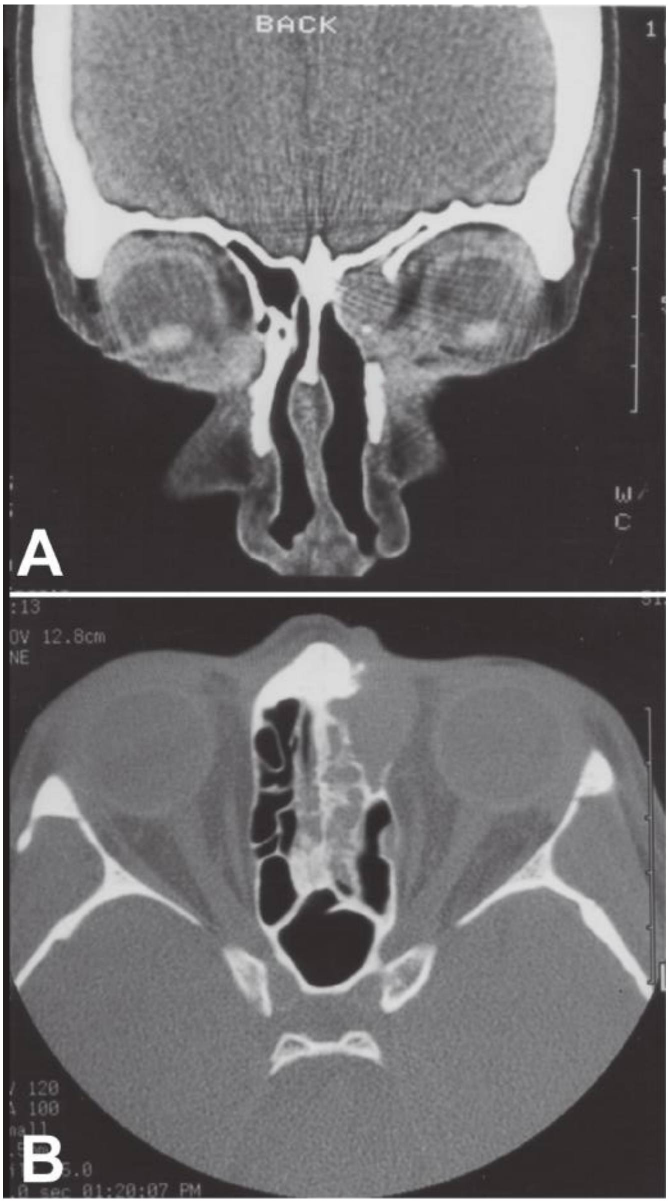


Fig. 19. A. Coronary and axial CT scan reveals ethmoido-frontal mucocoele at the left side, following frontobasal fracture 15 years previously.

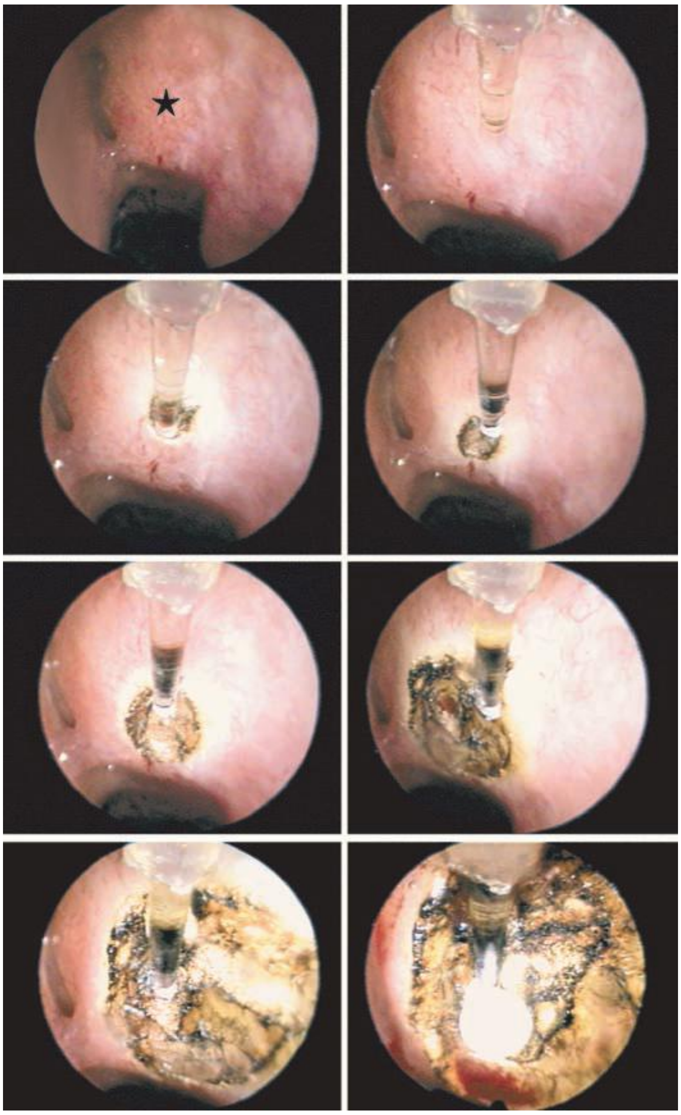


Fig. 20. Serial photographs showing endonasal view of the mucocoele situated to the left of the frontonasal recess, marked by a star. Stepwise superficial coagulation and vaporisation of the nasal surface of the mucocoele until the mucocoele contents are drained.

cal instruments, should be used with much care and skill.

Functional endoscopic laser surgery of the nose, paranasal sinuses, and nasopharynx (FEELS) is a low-risk, nearly painless and ambulatory method, which can be performed with surface anaesthesia. Due to its intraoperative haemostatic effect, it provides excellent view of the operation site. The technique is associated with low morbidity, does not require nasal packing, and patients are able to return to work within a short span of time.

The laser technique is particularly useful for certain high-risk groups of patients, such as poor anaesthetic risk, associated systemic pathology, and advancing age. In malignancy of the paranasal sinuses and the nasopharynx encroaching the nasal airway, the laser offers a good palliative management.

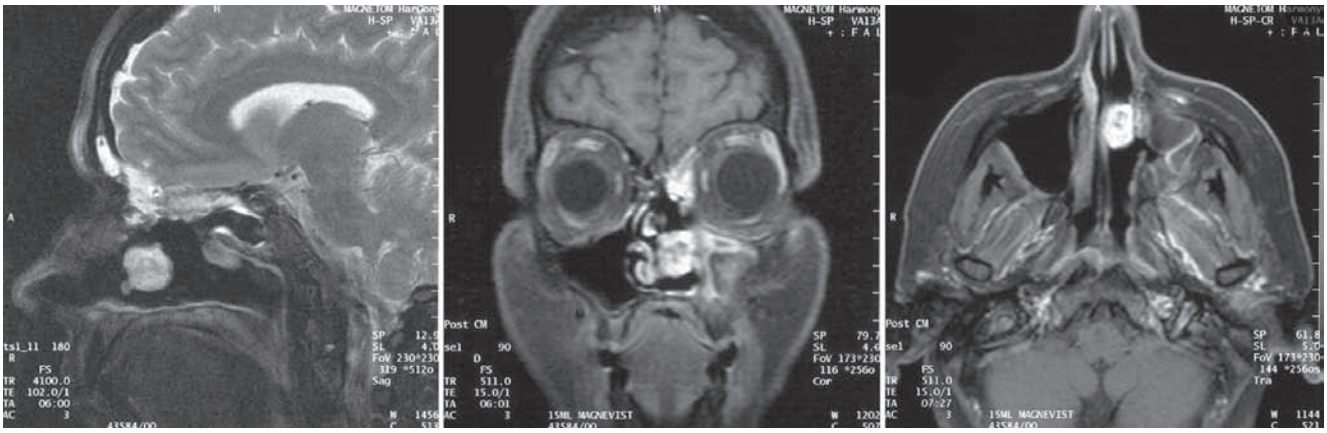
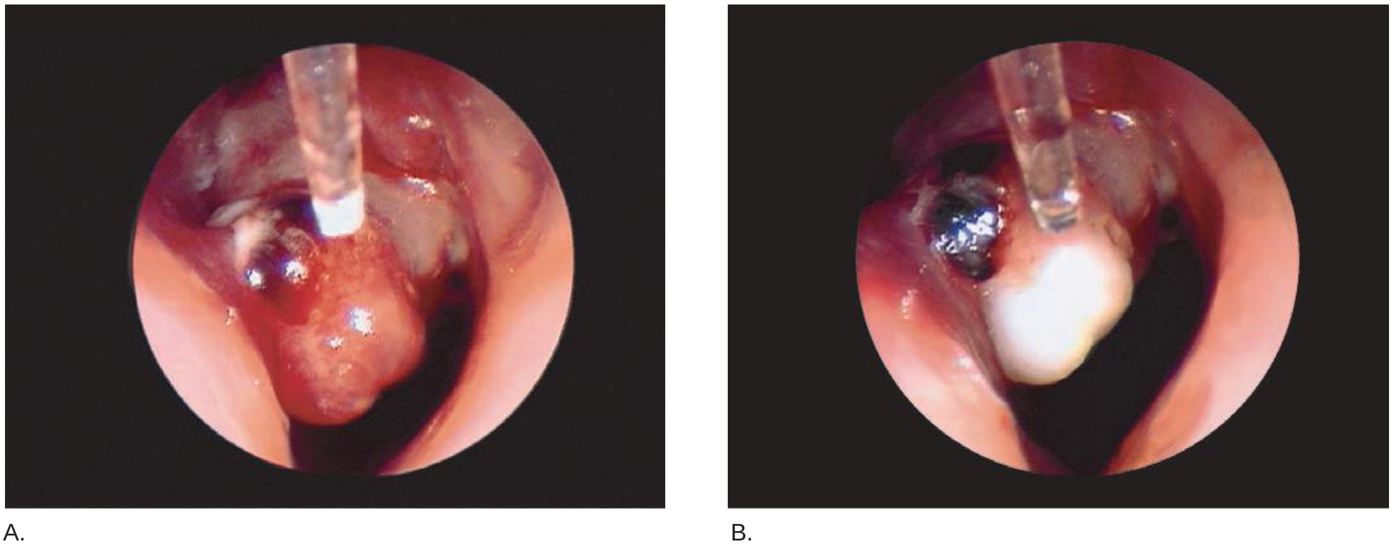


Fig. 21. Haemangioma of the left nasal cavity. MRI with gadolinium contrast shows marked vascularity.



A.

B.

Fig. 22. Laser management of cavernous nasal haemangioma. A. Cavernous haemangioma in the left nasal cavity originating from the septum. B. Diode laser treatment of the haemangioma in the chopped mode with 50-W power, 200-msec exposure time and an interval of 400 msec.

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MCQ – 24. Laser-assisted functional endoscopic sinus surgery

1. For any given setting, laser energy and therefore its effect on the tissue is controlled
   a. By varying the distance between the tip of the fibre and the target tissue
   b. By using the laser interstitially rather than on the surface
   c. By moving the beam rapidly over the large area of the tissue
   d. By purging cooling gas near the tip of the fibre
   e. All of the above

2. If during endoscopic laser surgery, bleeding is excessive, it should be controlled by
   a. Diathermy
   b. Continuous delivery of the laser energy to the bleeding area
   c. Withdrawing the fibre and striking the bleeder with defocused beam
   d. By packing the nose temporarily with ribbon gauze soaked in decongestant
   e. All of the above

3. While working with in the vicinity of vital structures
   a. The laser energy should be increased to remove the tissue efficiently so that there is no deep thermal spread
   b. The laser energy should be reduced so that the tissue is coagulated and removed bloodlessly
   c. A careful study should be made of the CT scan
   d. Laser should be used with stereo computer-guided surgery
   e. Laser should not be used

4. If the char is formed on the tissue due to laser strikes,
   a. Laser should be continually used to vaporise the char
   b. Char should be manually removed and laser strikes continued on fresh un-charred tissue
   c. Char is a protective barrier and should be left in situ to prevent postoperative infection
   d. The laser energy should be increased to vaporise the char
   e. All of the above

5. Postoperative care when laser is used for endonasal surgery
   a. Requires care which is no different than the usual care for functional endoscopic sinus surgery (FESS)
   b. Requires long term topical steroids
   c. Requires a course of antibiotic therapy
   d. Requires anti-allergic medication
   e. Requires periodic nasal douche

6. Aggressive laser usage for endonasal surgery can lead to the following complications
   a. Synechiae formation
   b. Anosmia
   c. Osteitis
   d. Granulation formation
   e. Postoperative infection

7. Use of Nd:YAG laser for bony removal
   a. Is very effective
   b. Results in prolonged widespread necrosis due to scatter
   c. Results in chronic osteitis

d. Should never undertaken
e. Should be undertaken with extreme caution

8. Septal spur
    a. In bilateral cases, it can be vaporised only on one side without causing any perforation
    b. In bilateral cases, it can be vaporised on both side with care, without causing any perforation
    c. Should only be vaporised when the other side is straight
    d. Should only be used if the spur is cartilagenous
    e. Laser should never be used for removal of the spur

Chapter 25

Lasers for endonasal (revision) surgery in chronic rhinosinusitis

J. Ilgner

1. Introduction

The main rationale for endonasal sinus surgery is the occurrence of chronic rhinosinusitis with or without polyps (CRS+NP or CRS-NP). This condition has a prevalence of about 11% in the general population, generating an impact on the health budget of about 4.3 billion US$ per year (Rosenfeld, 2007). Its aetiology is still not completely understood, although various hypotheses have been proposed relating the chronic character of rhinosinusitis to an infectious trigger by Staphylococcus aureus or fungi (Bachert, 2002; Ponikau, 2002; 2005).

2. Predisposition

Various predisposing factors have been suggested, these are: intolerance against non-steroid anti-inflammatory drugs in about seven to 22% of CRS patients, bronchial asthma in 19 to 46%, and allergic rhinitis in 22% while a general allergic disposition can be found in ten to 64% of patients (Larsen, 1997; Mehanna, 2002; Ragab, 2006; Seybt, 2007; Batra, 2003). Given such a variety of predisposing factors in a chronic inflammatory rhinosinusitis, it is now widely accepted that surgery is not the first option in the management of this condition. However, specific medical treatment options are still not a common place and thus, a large number of patients continues to be advised surgical management as the very first strategy.

3. The goal for surgical management

The rationale for a variety of surgical procedures is to remove grossly inflamed tissue from the ostiomeatal complex in the middle meatus, restore ventilation to the adjacent sinuses and enable drainage of mucus from these areas. The sinus mucosa is extremely prone to oedema and formation of polyps triggered by chronic inflammatory conditions, equally, it can heal quite well once the inflammatory reaction is contained. Thus the general approach established by Messerklinger and Stammberger in the 1970s entails endonasal surgery using optical devices (endoscope or microscope) to restore 'functional' element of the mucosa with minimal invasion (Stammberger 1986). However, surgery alone cannot completely roll back the chronic inflammatory process which is intrinsic in the nasal and paranasal mucosa. As a consequence, between ten and 27% of patients have symptomatic recurrence (Kennedy, 2002). It comes as a logical consequence that, in these patients, if postoperative medical regime fails, repeat surgery has to be advised, sometimes in many consecutive sessions. Since the 1980's, laser-assisted or laser-based surgical techniques have enabled both the initial as well as repeat surgery to be undertaken on a minimally-invasive scale.

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4. Literature review

4.1. The early years

Some of the early endonasal laser procedures addressed pathological lesions which were readily accessible. In 1973, Strong reported on the use of CO_2 laser to obliterate septal vessels in hereditary teleangiectasia and to remove solitary papillomas. He noted that, due to the energy delivery via a free beam, the application of CO_2 laser in the posterior area of the nasal cavity was limited (Strong, 1973; after Kass, 1993; Lippert, 1996).

In 1977, Lenz experimented with an Argon laser in nine human post-mortem specimens, which led to 14 procedures on patients, to enlarge the ostiomeatal complex. The medial maxillary sinus wall was opened, with removal of bone which ranged in thickness from 0.4 to 1.8 mm. The laser power ranged between 0.1 W and 100 W, and the beam diameter, between 0.5 to 1.5 mm.

4.2. CO_2 laser

In an experimental setup, Shapshay compared the endonasal tissue effects of a CO_2 laser with those of a Holmium:YAG laser. The CO_2 laser was operated at six W and fired in single shots of 0.1 to 0.5 s in continuous wave (cw) mode, it produced more carbonisation than Holmium:YAG laser with pulse energy of 1.0 to 1.2J at three to five Hz repetition rate. On the other hand, when the CO_2 laser was operated in superpulse mode at six W average power and 90 to 110 pulses per second, the reverse was true (Shapshay, 1991). Selkin summarised 250 endonasal procedures with CO_2 laser, along with complications. Among his cases, 61 were operated for hyperplastic inferior turbinates, 31 for bilateral polyps and 19 were for unilateral polyps (Selkin, 1986). He recorded a recurrence rate of endonasal obstruction in four cases, intra- and postoperative hameorrhage in 11 cases, septal perforations in two cases and Rhinitis sicca in one case. Laser parameters were not mentioned. Sato and co-workers used the CO_2 laser to ablate antrochoanal polyps in seven children and three adults (Sato, 2000). To increase the laser's working range, he used a set of angled handpieces deflecting the laser beam by 45°, 90° or 135° as needed. In another study by the same author, the removal of endonasal polyps was performed in conjunction with a microdebrider and laser in four cases and with CO_2 laser alone in another four cases. However, the majority of procedures were performed with a microdebrider alone (17 cases), while the bony margins of ostia were enlarged by conventional instruments.

4.3. KTP laser

Gerlinger (2003) published a series of 24 patients who suffered from bilateral chronic rhinosinusitis with polyps and were operated on one side according to FESS principles while on the other side KTP laser was used. Laser power was set between three and 30 W according to each task (control of bleeding vessels three to five W, polyp resection five to eight W, bone ablation 20-30 W). The total energy applied ranged between 484 and 1788 J. Soft tissue was resected in cw mode while bone was ablated in single pulses of 20 to 50 ms each. During postoperative care, pronounced oedema on the laser operated side was noted in the first postoperative week, while the FESS side showed a greater amount of crust formation. No other difference in wound healing was noted. The authors concluded that blood loss could be minimised with the use of a laser, while the disadvantages of laser surgery were increased cost for the laser system and applicators and longer operating time.

Levine (1997) used KTP laser in 46 patients to coagulate polyps in the postoperative follow up for FESS procedures. The KTP laser was used at six to ten W in non-contact mode with a defocused beam, in on-off intervals of 0.1 s each. Synechiae were also resected with the same system at eight to 12W. After 24 months follow up, 22 patients were recorded as symptom-free (15 patients under concomitant medical treatment for CRS), 18 as improved (17 with medication), four unchanged and two worse.

Wang (2003) published his experience with 13 patients specifically undergoing endonasal revision surgery for recurrent chronic rhinosinusitis. KTP-laser power was set between 15 and 20 W cw. Laser energy was applied by a bare fibre of 400 µm diameter with a 400 µm spot size in contact and 800 µm spot size in non-contact mode. Polyps were either excised from the base, or vaporised. Over an average postoperative period of 24.7 months, two patients showed further recurrence of disease. No complications were reported.

4.4. Holmium:YAG laser

Many authors have evaluated the use of Ho:YAG lasers for endonasal procedures. Among others, Gleich and co-workers performed 37 operations, of which 29 were indicated for chronic rhinosinusitis (Gleich, 1995). Ten patients had been operated on before by FESS or Caldwell-Luc technique. While polyps were resected with pulse energy of 0.8 J at 3 Hz repetition rate, bony structures were opened with a higher energy of one J and three Hz. Twenty-four out of 29 patients were described as symptom-free thereafter, one patient had to be revised for recurrent polyps and another suffered postoperative haemorrhage. The authors noted that postoperative wound healing was not prolonged compared to FESS surgery.

Kautzky, Bigenzahn and co-workers reported ten interventions for chronic rhinosinusitis with Ho.YAG laser (Kautzky, 1992). They used a 600 µm glass fibre, while their power settings were similar to Gleich's (0,9 J pulse energy, five Hz repetition rate). The laser was used to incise only bone, while conventional biting forceps were employed to remove it. The authors emphasised that there was a marked zone of bone necrosis (370-520 µm), but no carbonisation was seen. Wound healing was described as uneventful. Kautzky *et al*. (1992) and Shapshay (1992) also noted that tissue debris contaminates the endoscope's lens thereby impairing vision.

In a prospective, randomised controlled trial, Metson enrolled 32 patients with bilateral CRS, who were operated with the Ho:YAG laser on one side, and with FESS technique on the other side (Metson, 1996). Laser energy was transmitted via a 400µm glass fibre, pulse energy varied between 0.5 and two J, at a repetition rate of 5 to 7.5 Hz, resulting in an average power of 2.5 to 15 W. Blood loss was markedly less on the laser operated side, while the whole operative procedure took 121 minutes on average, which was considerably longer than with FESS technique alone. In the postoperative period, oedema appeared more pronounced on the laser-treated side. Crusts were more apparent on the conventional side after week one but more prevalent on the laser-operated side after six weeks, where crusts were noted to cover small bony sequestrae. Ablation depth was estimated between 1.2 and 1.7 mm, whereas the adjacent thermal necrosis zone extended to 0.5 to 1.0 mm.

Following his experience in animal experiments, Shapshay published a series of 17 patients whom he operated with a Ho:YAG laser to resect the uncinate process, open the ethmoid bulla and the maxillary sinus ostium, while the ethmoid cells were opened conventionally (Shapshay, 1991; 1992). The average operation time was 1 h 50 m. The total energy varied between 380 and 5048 J at pulse energy of 0.5 to 1.2 J, repetition rate of three to ten Hz. In ten patients the result was noted as 'excellent', four patients described partial re-obstruction of the nose and three patients had recurrent polyps after six to eight months.

4.5. Neodymium:YAG laser

While a considerable body of literature exists on the use of Nd:YAG laser for turbinate reduction, the number of studies on Nd:YAG laser use for CRS is rather limited.

Ohyama (1989) employed the Nd:YAG laser in 21 patients to shrink polyps interstitially and resect these polyps in a bloodless manner from the stalk. He noted a prolonged appearance of crusts for two weeks following this technique. The duration of the procedure was prolonged, although blood loss was negligible. Long term results and laser parameters were not given.

Zhang (1993) used the Nd:YAG laser in non contact mode at 25 W cw to superficially coagulate the mucosa along the ethmoid walls following polypectomy from the nasal cavity and ethmoid cells. In contrast to 48 conventionally treated patients, 54 laser treated patients were described to run a smaller risk of polyp recurrence (46,6% versus 66,6%).

There has been extensive work by Scherer and Hopf (2001) on *recurrent* chronic rhinosinusitis controlled with Nd:YAG laser interventions. In one study, Scherer explicitly used the Nd:YAG laser to resect polyps from their base in the middle meatus in contact mode at three to five W cw (Scherer, 1999) under endoscopic guidance by means of a dedicated combined instrument for laser fibre guidance and monitoring.

5. Indication for endonasal laser surgery for CRS

Laser surgery for chronic rhinosinusitis, especially in revision cases, cannot be indicated as an isolated measure but has to be regarded as one option in the course of disease control. We developed an algorithm that puts laser surgery for CRS in context

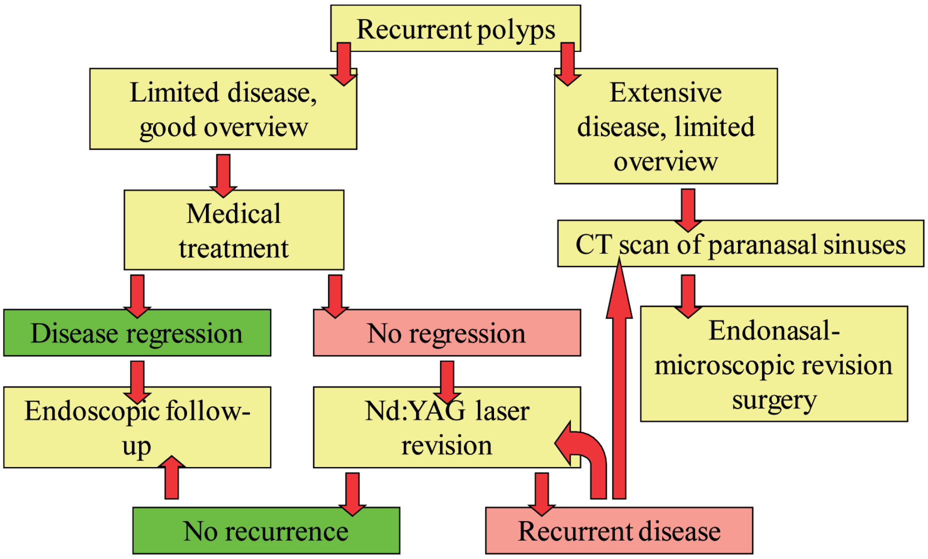
Recurrent polyps
Limited disease, good overview
Extensive disease, limited overview
Medical treatment
CT scan of paranasal sinuses
Disease regression
No regression
Endonasal-microscopic revision surgery
Endoscopic follow-up
Nd:YAG laser revision
No recurrence
Recurrent disease

Fig. 1. Algorithm showing the role of Nd:YAG laser revision surgery for chronic rhinosinusitis (centre) embedded in a treatment strategy.

with non-invasive measures on the one hand, and re-assessment by CT scan and revision FESS on the other (Fig.1).

Generally, endonasal laser revision surgery is the treatment of choice if there is disease recurrence with polyps that do not regress on immuno-modulatory medication (topical steroids, systemic steroids, antihistamines, leukotriene antagonists etc.) These polyps are prone to block key structures, such as the ostiomeatal complex, the sphenoid or the frontal sinus ostia, thus cutting off sinus areas from ventilation, which is likely to exacerbate the inflammatory process. Ideally, at any particular laser session, up to three regions out of five (anterior ethmoid, posterior ethmoid, maxillary sinus ostium, frontal sinus recess, sphenoid sinus ostium) should be addressed. If more than three regions are involved, then management over two or more sessions is advised.

5.1. Contra-indications for endonasal laser surgery for CRS

Polyps should not trespass the boundaries of typical landmarks, *e.g.*, the periorbit, the middle meatus or cover the whole of the superior area of the inferior turbinate, to ensure that the orientation in most of the ethmoid areas is maintained. Furthermore, a history of CSF leakage, orbital fat prolapse due to dehiscence of the periorbit or excessive bleeding in pervious interventions is also a contraindication. Arterial hypertension should be controlled before embarking upon endonasal laser surgery under local anaesthesia.

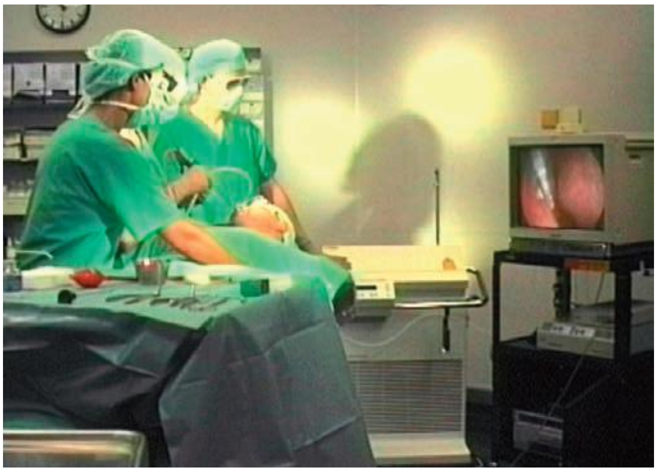

Fig. 2. Intraoperative setup for endonasal laser revision surgery (from left): scrub nurse, surgeon, assistant, patient , Nd:YAG laser system, video monitoring and recording unit.

6. Preparation

The patient is placed on the operating table in a supine position with his chest and head elevated at 30°. The surgeon's position is maintained to the patient's right side, as with standard FESS procedures (Fig. 2). Laser safety precautions are observed as in any other type of laser surgery. The patient as well as all members of staff are provided with laser safety eyewear. In case of general anaesthesia, patient's eyes are covered with a layer of aluminium foil and also a layer of non-sterile gauze soaked in water. Aluminium foil can be omitted if a laser wavelength with strong absorption in water is used. The patient's head is slightly rotated towards the surgeon.

For local anaesthesia, several bouts of 10% lidocaine spray for each nasal cavity is used. Next, the endonasal mucosa is decongested by the use of cotton swabs containing a mixture of oxymetazoline 0.1% and lidocaine 2% solution. Having left these swabs in place for ten minutes, they are removed and the endonasal mucosa is mechanically cleared of mucus and crusts.

7. Laser system (negative feedback control)

As mentioned before, various laser systems are suitable for endonasal procedures. While considering a particular laser for endonasal use, the specific properties in laser-tissue-interaction, physics of energy delivery and propagation in human tissue and the relevant laser parameter settings are taken in to account and tailored to the desired effect. In this context, we have been using Nd:YAG laser system (Dornier MediLas 5060N, Dornier GmbH, Germering, Germany). In order to control penetration depth, contact-mode or near-contact mode (~1 mm distance from target tissue) is maintained throughout the procedure. For contact-mode use, the laser fibre is charred at the tip by briefly firing a wooden spatula at ten W.

The output power is usually set at ten W (cw) in most cases and 20 or 30 W in selected conditions. In order to prevent tissue from receiving excessive amount of energy, the laser system is equipped with a negative feedback power control circuit Fibertom(C). As the tissue heats up under laser radiation, it will eventually start to burn (carbonise) superficially, thus resulting in a red to yellow glow. This visible glow is transmitted back via the laser fibre into the laser system, thus giving a signal to the laser control unit to lower the energy level until the tissue is dissected but not 'burnt' (Fig. 3). This system allows the use of continuous wave mode without excessive temperature rise and yields more predictable results with low carbonisation margins and less coagulation artefacts. It goes without saying that the feedback mechanism is only functional in contact mode.

7.1. Laser fibres

Generally speaking, the use of lasers with fibre-transmissible wavelength is preferred to free beam lasers which do not allow directing laser energy off the straight axis. Although the use of hollow waveguides, *e.g.*, for CO_2 lasers, is making progress, these waveguides are still far less flexible than quartz silica fibres used in visible light range or near infrared. Moreover, hollow-wave guides, too, are single use specification and thus, expensive.

Using quartz silica fibres, a whole range of

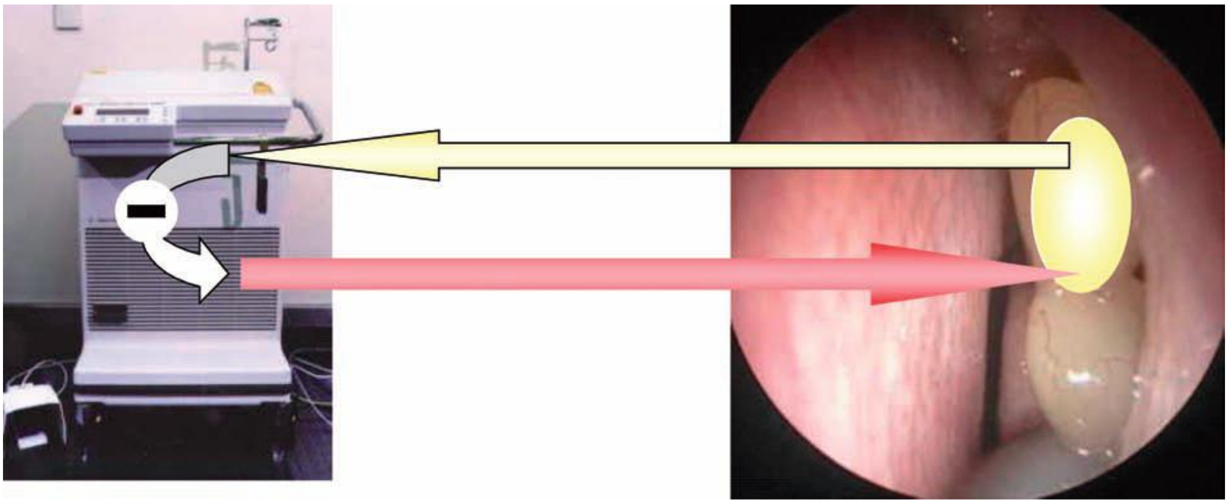

Fig. 3. Principle of negative feedback laser power control: The glow of carbonising tissue (yellow arrow) is transmitted via the laser fibre into the laser system and is used as a parameter to reduce the emitted laser power (red arrow).

diameters can be employed successfully. In the past we have been using fibres with a core diameter of 200, 400 and 600 µm respectively. Including cladding and sheeting, the effective diameter can vary between 240 and 1100 µm. 600 µm fibres can carry almost any amount of laser energy delivered by the system, even powers that are far in excess of those needed for endonasal surgery. While using smaller fibres, it has to be kept in mind that the energy density across the fibre area increases by the power of two while the diameter decreases linearly. This does not necessarily mean that the spot size coming out of the fibre becomes wider with smaller fibre diameters, as this varies with the design of optical coupling devices on the laser system side. We have observed a laser spot size of seven mm diameter for a 600 µm diameter fibre, at a target distance of 20 mm (Fig. 4). This compares to eight mm spot size for a 200 µm fibre (Fig. 5).

Although laser fibres are generally single use material and do not require the laser fibre tip to be cleaved, this sometimes becomes necessary due to soiling or fracturing of the fibre tip. In this case, the beam *shape* must be re-checked before entering the patient, particularly when working in non-contact mode since the fibre tip often breaks irregularly even when cut with dedicated device, thus altering the beam shape quite drastically (Fig. 6).

7.2. Instruments for laser energy delivery

Hopf, Scherer and co-workers, in cooperation with Karl Storz GmbH, Tuttlingen, Germany have developed a combined endoscopic laser delivery instrument with an Albarran lever mechanism that allows deflection of the laser fibre in a range between -5 and +45°. The advantage of this instrument is that it facilitates handling of the laser fibre which always remains in the line of sight. The instrument also prevents it from slipping from tissue contact. Moreover, one single instrument takes much less space inside the nasal cavity.

On the other hand, although two-handed approach with separate handling of endoscope and laser fibre applicator requires a greater amount of manual skill, it can be advantageous as the endoscope can be steered independently in certain situations, *e.g.*, when debris or small amount of blood next to the laser fibre tend to obstruct the view or when a greater overview of the operative field is required for orientation. In a two-handed approach, the laser fibre applicators can be very simple. Initially, we started

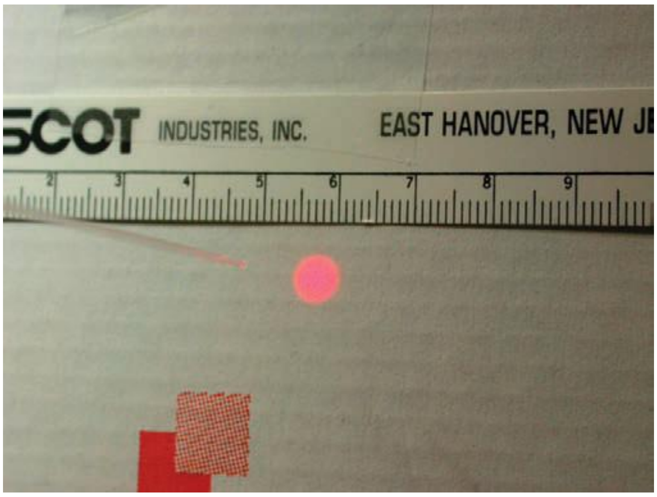

Fig. 4. 7 mm spot size of a He:Ne aiming beam from a 600µm laser fibre at 20 mm distance (MediLas 5060N, Dornier GmbH, Germering, Germany).

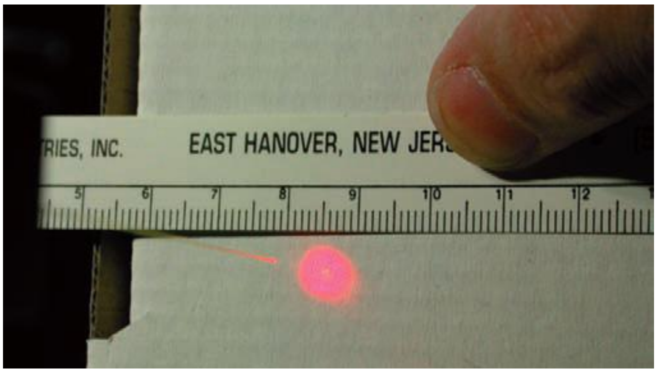

Fig. 5. 8.mm spot size of a He:Ne aiming beam from a 200µm laser fibre at 20 mm distance (MediLas 5060N, Dornier GmbH, Germering, Germany).

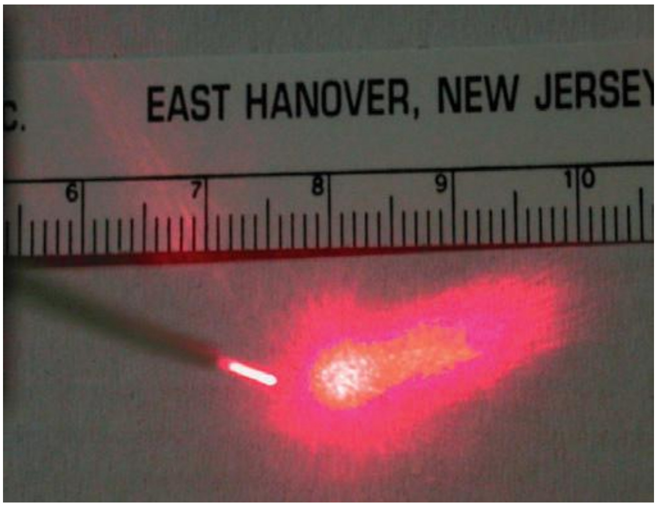

Fig. 6. Irregular spot geometry of a He:Ne aiming beam from a cut 600 µm laser fibre at 20 mm distance (MediLas 5060N, Dornier GmbH, Germering, Germany).

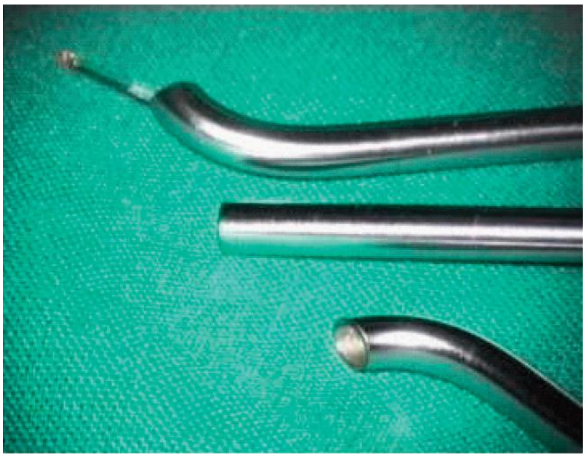

Fig. 7. 45° angled and straight rigid single-channel steel tube applicators with inserted 600µm fibre (top).

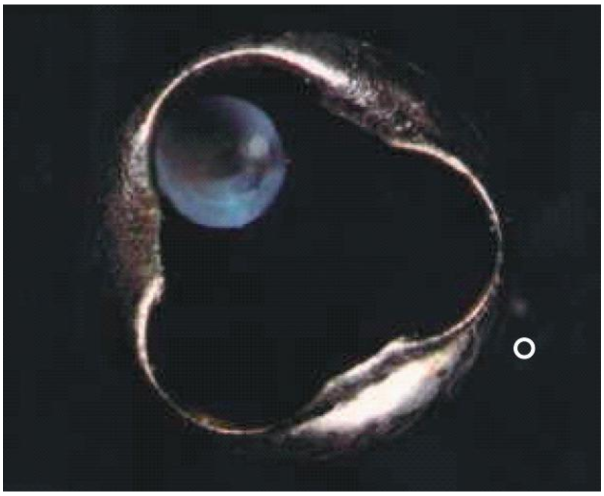

Fig. 8. Front view of straight rigid single-channel steel tube applicator with inserted 600 µm fibre.

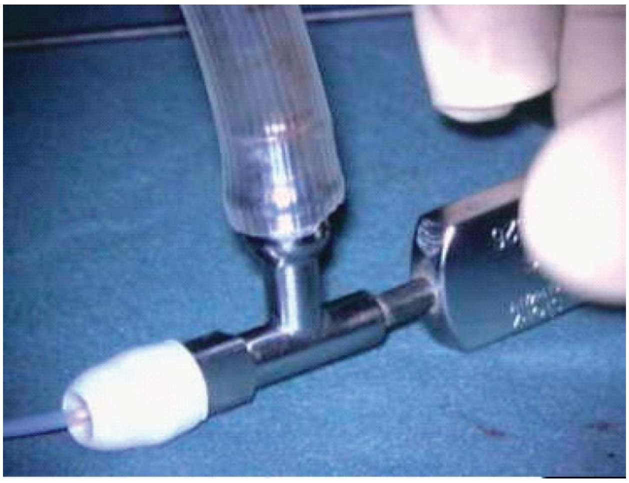

Fig. 9. Connector side of rigid single-channel steel tube applicator with inserted 600 µm fibre in airtight rubber plug (axial tap, left) and smoke evacuation tube (lateral tap, top).

off with a set of rigid steel suction/irrigation tubes, whose tip is bent at 45 and 90° to the right or left respectively (Fig. 7). The single channel accommodates the laser fibre up to 600 µm core diameter and also leaves enough lateral space to evacuate laser plume (Fig. 8). Thus, the axial connector is needed to feed the fibre through an airtight rubber plug while the lateral tap is connected to the smoke evacuation device (Fig. 9). The disadvantage is that it is difficult to force a strong laser fibre through a sharp 90° angle, increasing the risk of fibre core fracture.

Alternatively, we developed a semi rigid applicator (PolyDiagnost GmbH, Pfaffenhofen, Germany) with a flexible tip of 25 mm in length which can be bent to a 180° angle unloaded, which is reduced to 120°, accommodating a 200 µm core fibre (Figs. 10

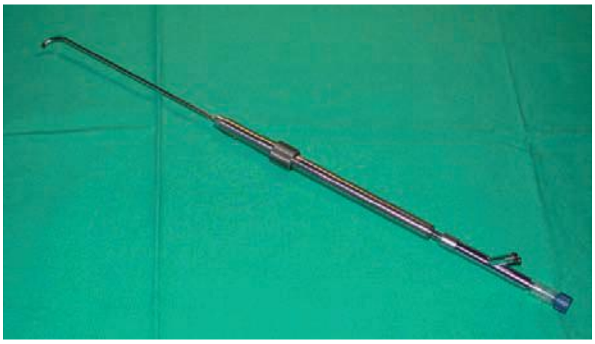

Fig. 10. Full length of semi-flexible applicator with deflected tip (top left) and controller ring (centre) (EndoFlektor, Polydiagnost GmbH, Pfaffenhofen, Germany).

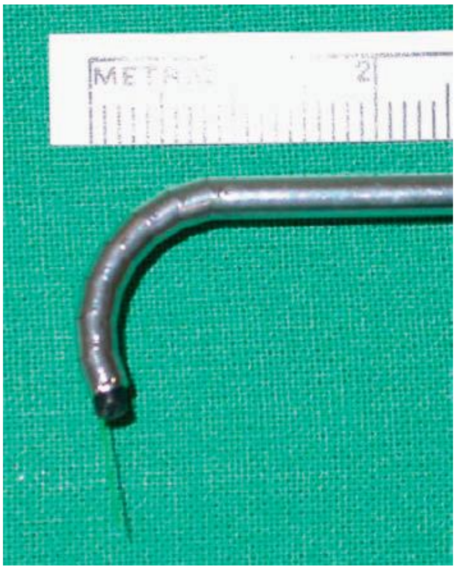

Fig. 11. 120° deflected tip of semi-flexible applicator with inserted 200 µm laser fibre (EndoFlektor, Polydiagnost GmbH, Pfaffenhofen, Germany).

Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery, edited by V. Oswal, et al., Kugler Publications, 2014. ProQuest Ebook Central,

and 11). Practically, this fibre diameter can only take a limited amount of power (14 W cw for Nd:YAG laser) without being destroyed. However, due to the higher energy density at the fibre tip this has proved sufficient to resect all parts of soft tissue in contact mode. As thinner laser fibres are more flexible than thicker ones, the risk of fibre fracture is reduced even at bend angles of 120°.

Another point that is often overlooked is that laser fibres suffer an exponential loss of energy transmission with greater bend angles, which sets in at smaller angle values for thicker fibres than for thinner fibres. Thus, when 600 µm laser fibre is further bent from 45 to 90°, the amount of energy available at the laser fibre tip can be lower than with a 200 µm fibre. The amount of energy that is lost in the bent fibre section contributes to unwanted heating of the metal tube.

7.3. Smoke evacuation

A separate smoke evacuation unit (Draeger Suction System SuSy, Draeger GmbH, Lübeck, Germany) is employed throughout the procedure to remove smoke and aerosols from the relatively small sinus cavities. The evacuation duct is connected via a standard tube to the lateral tap of the rigid applicators or the respective Luer-Lock® tap of the semi-flexible applicator. Although the smoke evacuation canal in the semi-flexible applicator is quite small in diameter (Figs. 12 and 13), it is entirely sufficient for a 200 µm fibre which cuts precise margins with very little carbonisation at ten W maximum. For suction of fluids (blood, secretion, etc.) a standard theatre suction unit is provided.

7.4. Endoscopes

Standard four-mm endoscopes with 30° and 70° viewing angle (Storz 7210 BWA and 7210 CWA, Storz GmbH, Tuttlingen, Germany) are used. Due to off-axis manoeuvrability of the laser fibre, there is no real use for operating microscopes in this particular setting. On the down side, mucus and particularly small amounts of blood frequently obstruct the view through the endoscope, requiring frequent interruptions for lens cleaning. In this context, flushing endoscopes with constant irrigation of the lens can provide an alternative.

7.5. Video monitoring

As with most endoscopic surgery, irrespective of the surgical field, digital image processing now allows the surgeon to monitor and guide the position of the laser instruments and the endoscope in real time from a standard video monitor. In our setting, we have been using an analogue 3CCD endoscope camera (Lemke TC 804, Lemke GmbH, Gröbenzell, Germany) attached to the endoscope. The signal is fed in parallel to a digital video recorder (Sony DSR35, Sony Corp. Tokyo, Japan) and into a video monitor of the same manufacturer. The equipment delivers standard resolution (720 x 576 pixels) which is adequate for undertaking the procedure safely. However, with further advances in digital image processing, endoscopic CCD camera heads providing HD (D4) resolution (1280 x 720 pixels) or even Full HD (1920 x 1080 pixels) resolution have become widely available and not prohibitively expensive. Further developments have been marketed recently, *e.g.*, a stereo-endoscopic monitoring system at near-standard resolution for an endoscope with outer diameter of four mm

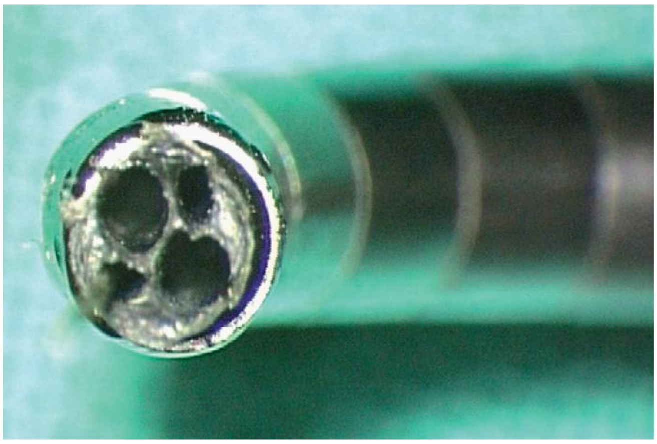

Fig. 12. Front view of applicator tip with inner sheath (EndoFlektor, Polydiagnost GmbH, Pfaffenhofen, Germany).

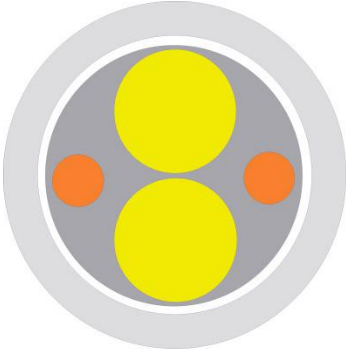

Fig. 13. Compartment scheme of inner sheath shown in Fig. 12. Two channels with 300 µm which accommodate a 200 µm laser fibre and two channels with 1200 µm for smoke evacuation and/or irrigation.

(Vision Sense®, marketed by Carl Zeiss Surgical, Oberkochen, Germany). It is to be expected that flexible endoscopes with small diameters (four mm or less) will be equipped with CCD image sensors ('chip on a tip') and thus overcome the resolution limits by the number of glass fibres in conventional flexible endoscopes.

8. Surgical technique

8.1. Polyps

Polyps appear as flabby, pedunculated and grey to amber-coloured masses that arise from the mucosa. Due to their high water content, they can be shrunk before resection or, if the stalk is readily identifiable, resected while leaving the stroma intact (Fig. 14). Shrinking polyps can be achieved in near-contact mode at a distance of about one mm, taking care of the surrounding anatomy. Due to the loss of energy density with increasing distance from the tissue surface which is diminished to the power of four, higher power settings are required for a non-contact laser application compared to contact mode. The surgeon should be aware that Nd:YAG laser, emitting at 1064 nm, is not efficiently absorbed by water or chromophores, but is scattered along irregular surfaces. Thus the energy deposition is only 50% at about four mm penetration depth, depending on tissue density, while another 50% is propagated to deeper layers. In contact mode, however, the penetration depth is minimised to less than one mm, thus making laser resection much less prone to cause adverse effects. In addition, cutting a polyp off its base with brush-like strokes of the laser fibre leaves its content unaltered. Thus, the tissue is available for further histological examination, which helps determine postoperative medication pathways (*e.g.*, predominance of Neutrophils versus Eosinophils in the stroma).

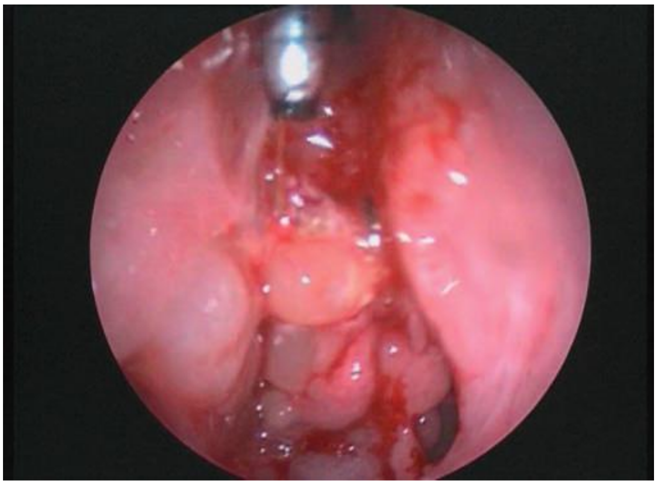

Fig. 14. Flexible applicator with 200 µm laser fibre resecting a polyp blocking the frontal recess in the right anterior ethmoid region (Nd:YAG Laser, 10 W, cw, with negative feedback power control).

8.2. Synechiae

Synechiae usually occur between the nasal septum and the medial wall of the middle or inferior turbinate. Their formation is initiated by loss of mucosa on apposing surfaces which develop granulating tissue during wound healing and is facilitated by bridges of mucus or crusts in postoperative phase, if not detected early enough by the surgeon in one of the follow-up sessions. They can be reliably removed by excision in contact mode. To our experience, if two resection lines are created on either side of the base (septum and turbinate), the gap in between is wide enough prevent recurrence, avoiding the need for silicone sheet spacers. In contact mode, thermal damage to submucous tissue is limited to less than 1mm, which lowers the risk of granulating tissue formation and thus for recurrence of fibrous tissue across the endonasal cavity.

8.3. Mucocoeles

Mucocoeles can be resected in contact mode ideally, if a substantial portion of their circumference can be reached with a laser fibre tip (Fig. 15). Under these conditions, part of the wall can be resected in contact mode, while the content provides heat sink as long as the fluid does not leak from the cystic mass. Incision alone will not prevent the wall from re-closure, with recurrence.

8.4. Granulating tissue

Granulating tissue sometimes overgrows the endonasal wound during the wound healing process following FESS, so that the occurrence of postoperative complications becomes likely. Granulating tissue is populated with fibroblasts and fibrous restenosis and synechia formation occurs. It has to be emphasised that granulating tissue is part of the normal postoperative wound healing process and as such, its appearance should be addressed with topical steroids, systemic leukotriene-antagonists etc. first. However, in selected cases, removal of excess granulating tissue can be helpful in order to guide local wound restoration to prevent scar formation (Fig. 16). Care should be taken that thermal damage to the tissue is limited by applying less power and using contact mode only in order to diminish the trigger for more granulations to appear.

9. Outcome

From a cohort of 175 Nd:YAG laser revision procedures and 268 FESS revision surgeries for the *recurrence* of chronic rhinosinusitis, we compared features of wound healing at various intervals by taking histological samples from 16 patients following laser revision and 14 patients after FESS revision.

Histology of resected tissue *ex vivo* shows limited zones of thermal damage when 10W cw of laser power are used in contact mode employing negative feedback power delivery control. As energy density is higher in a smaller fibre diameter, there was no carbonisation zone when 200 µm was used. The coagulation depth was about 30 µm. In comparison, when 600 µm fibre was used, the carbonisation zone was less than 10 µm thickness with an adjacent coagulation zone varying between 75 and 200 µm thickness (Figs. 17 and 18). In both cases, the rest of the tissue was unaltered, which allowed reliable histological examination.

The chronological observations were made in respect of the appearance of fibrin, oedema, prevalence of granulocytes, lymphocytes, collagen, and epithelialisation (with squamous cell epithelium versus respiratory epithelium). Although the number of samples for histological specimen was too small for statistical analysis, significant difference was seen in the prolonged appearance of tissue oedema following laser surgery. This effect was also seen by Metson (1996) when comparing laser resected endonasal areas on one side to conventionally resected areas on the other side intraindividually. This single difference apparently has no impact on further course of wound healing.

From our aforementioned series, we also compared ‘survival rates’ of both surgical modalities. ‘Survival’ in this context was defined as the time interval from the operation to symptomatic re-appearance of polyps, re-stenosis of paranasal sinus ostia etc. in chronic rhinosinusitis, requiring revision surgery – be it another laser session or a full FESS revision procedure. As expected, the incidence of revision surgery was greater in those who had undergone previous revision surgery than those who have had only primary surgery. However, within the group of patients having had one revision the survival rate without re-intervention was not statistically different for laser versus FESS revision patients (P = 0.1529).

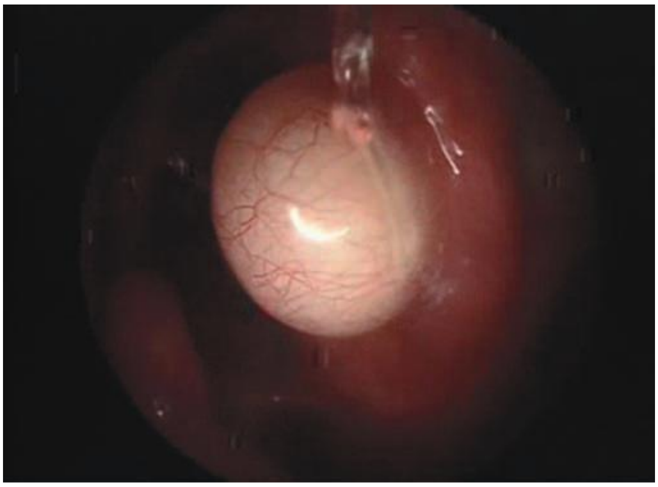

Fig. 15. Straight, rigid applicator with 600 µm laser fibre incising the edge of a mucocoele next to the left maxillary sinus ostium (Nd:YAG Laser, 10 W, cw, with negative feedback power control).

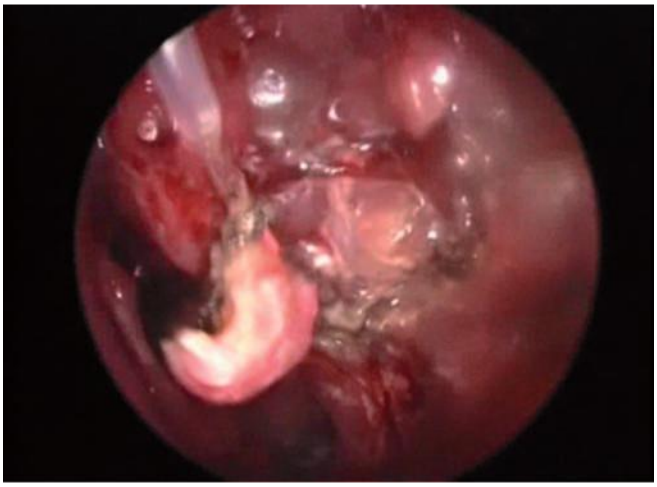

Fig. 16. 90° curved rigid applicator with 600 µm laser fibre resecting granulating tissue at the edge of the right maxillary sinus ostium (Nd:YAG Laser, 10 W, cw, with negative feedback power control).

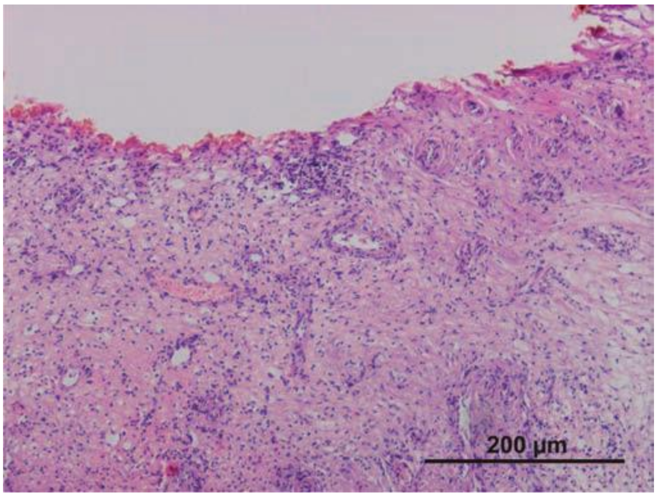

Fig. 17. Histology slide of a laser resected polyp specimen (haematoxylin-eosin stain, 10 x magnification in chronic rhinosinusitis (Nd:YAG Laser, 10 W, cw, with negative feedback power control, 200 µm fibre, contact mode). The carbonisation margin is not detectable, the coagulation zone width from the laser energy impact (from top) is 30 µm on average.

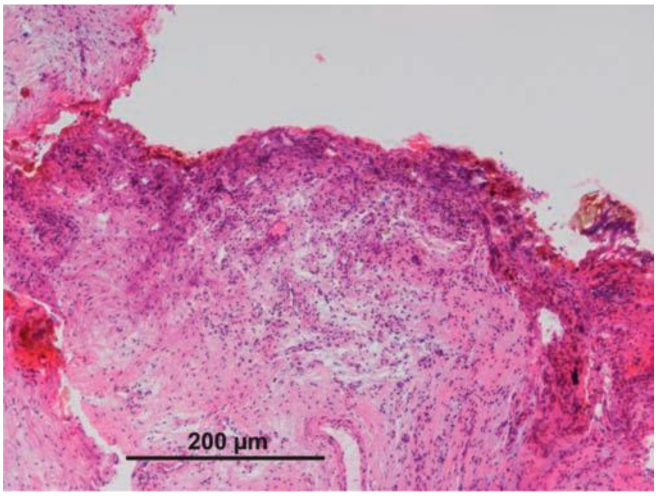

Fig. 18. As Fig. 17, but excised with a 600 µm fibre. Carbonisation margin is less than 10 µm wide, coagulation zone width is 75 to 200 µm.

10. Risks of endonasal laser revision surgery

A number of risks have been attributed to the endonasal use of lasers.

Lesserson emphasised the deep coagulating properties of Nd:YAG laser radiation in the endonasal mucosa (Lesserson, 1984). Because of these properties, Lenz and Eichler (1984) as well as Metson (1996) argued that the marked scatter of laser radiation by irregular surfaces at 1064 nm would put adjacent structures at risk due to unwanted radiation. Those potential risks have been confirmed by data considering the use of Nd:YAG laser in non-contact mode only. Werner (1992) observed a thermal damage zone of 10 mm maximum, irradiating endonasal soft tissue in non contact mode. Rathfoot (1996) reported ‘collateral damage’ in tissue up to four mm depth. Ossoff (1994) described a tissue coagulation/necrosis zone up to four mm. Werner, in addition, warned against atrophying osteitis of underlying bone in non-contact laser radiation. However, the underlying laser parameters are not always mentioned so complete understanding of tissue effects from aforementioned studies is limited. Nonetheless, other authors have concluded to use Nd:YAG lasers endonasally only for removal of small lesions as endonasal papilloma or alternatively in the lower third of the nasal cavity and the inferior turbinate, respectively (Jovanovic, 1995; Lippert, 1996; Ossoff, 1994; Rathfoot, 1996; Slatkine, 1994). However, only a minority of authors have, in their studies, differentiated between the use of Nd:YAG laser in contact versus non-contact mode (Scherer, 1999; Shapshay, 1992). Hopf and Scherer have limited the use of Nd:YAG laser to contact mode and power settings of three to five W cw. Shapshay (1992) has also employed this system in contact mode and could not observe any collateral damage to deeper or adjacent structures. Shapshay only mentioned resected polyp tissue sticking to the laser fibre, requiring meticulous cleaning of the tip.

To put these observations and hypothesis in perspective, two factors have to be mentioned. First, endonasal laser surgery, as any other surgical technique, requires judicious setting of indication for this type of surgery, not to mention general surgical experience in the use of lasers as well as in non-laser FESS. Visibility has to be maintained at all times so that the surgeon can judge the effect of laser treatment in relation to adjacent structures. Secondly, all adverse events during wound healing have to be set off against the natural course of chronic rhinosinusitis, as surgery can only modify endonasal anatomy but cannot eradicate the inflammatory process itself.

In everyday practice, the actual occurrence of adverse effects is a highly unlikely event.

In our series of 101 patients, we performed a total of 175 endonasal-endoscopic laser revision interventions using the Nd:YAG laser in *contact* mode with negative feedback power supply. In six cases, the procedure had to be stopped due to intercurrent bleeding from the resection site caused by arterial hypertension, which impaired endoscopic vision. The bleeding, however, was controlled intraoperatively but further resection was deferred to another date when arterial hypertension was controlled properly. In two further cases, sensory loss was observed in the region of the infraorbital nerve following laser polyp resection in the ostiomeatal complex area. This occurred several hours after the procedure and resolved spontaneously about six weeks later. Other than that, no complications, notably to the anterior skull base or the orbit, occurred.

11. Benefits of endonasal laser revision surgery

Considering the relatively benign course of chronic rhinosinusitis, one surgical session usually controls the disease for most patients. These patients are prescribed long term topical or systemic anti-inflammatory medication and are monitored at regular intervals. For some patients, medical treatment alone fails to relieve their symptoms. These patients then require further, and sometimes, repetitive surgical interventions. Endoscopic endonasal laser revision surgery is a viable option for the following reasons:

- Minimal blood loss during surgery, thus reducing post-operative risk of haemorrhage;
- Nasal packing is seldom required;
- Small endonasal wound areas facilitates re-epithelialisation;
- Ambulatory surgery under topical anaesthesia is feasible;
- Ambulatory surgery is cost effective (see below).

Other benefits under consideration include a hypothesis that laser irradiation of the inflammatory process, *e.g.*, with a KTP laser, could initiate a shift in T-cell population for the benefit of Th1 helper cells, thus contributing to control of chronic rhinosinusitis at cellular level. However, further data to this hypothesis are not available yet (Mori, 2003).

12. Cost-effectiveness

Laser technology is expensive and requires a considerable amount of capital outlay. Most laser fibres are specified by the manufacturers for single use, which adds to the revenue cost for each case. Although ambulatory surgery is a lot cheaper, full reimbursement from insurers may not be forthcoming.

It could be shown that ambulatory laser-based endonasal revision surgery yields long-term control of the disease comparable to FESS revision surgery, thus making the laser procedure overall cost-effective compared to an in-patient hospital stay including post-operative downtime and absence from work.

13. Alternatives to laser revision surgery

One alternative to endonasal laser revision surgery that has come up in the 1990’s is the use of powered instruments, *e.g.*, microdebriders (Kennedy, 2006; Grevers, 1995; Selivanova, 2003). While microdebriders allow quicker removal of soft tissue, wider view of the operative field during the actual resection procedure can be limited. The patient is left with an open, non-coagulated wound, thus raising the risk of intra-operative and post-operative bleeding. According to the European Position Paper on Polyps and Chronic Sinusitis (EPPPOS, Fokkens *et al*., 2007), the outcome of standard FESS, FESS with specific through-cutting instruments (Vauterin, 2006), the use of powered instruments and laser surgery has not yielded any difference in disease control status after one year (Selivanova, 2003).

14. Discussion

In conclusion, endonasal laser surgery for revision cases of chronic rhinosinusitis is a feasible alternative to full-fledged FESS revision procedures in selected cases. As with any other surgical procedure, there are certain constraints. The overall extent of the disease must allow orientation of adjacent structures and access to the surgical site should not be impaired by obstructive disease process. It is necessary for any prospective endonasal laser surgeon to acquire competent training in FESS. In addition, the knowledge of laser-tissue interaction for a given laser system and the correct choice of parameters are of utmost importance. The potential hazards of endonasal laser surgery can be controlled well and the patient is provided with a valuable ambulatory option in treating his particular disease.

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MCQ – 25. Lasers for endonasal (revision) surgery in chronic rhinosinusitis

1. Rationale for laser usage in Chronic Rhino Sinusitis (CRS) as the first line of management is indicated in
    a. Polyps involving nasal cavity and sinuses
    b. Extensive sinus disease
    c. Limited nasal polyps involving nasal cavity and sinus ostia
    d. In cases of recurrent disease where polyps mainly occur in nasal cavity and sinus ostia
    e. In cases which are resistant to medical management

2. Laser usage for polyp removal is contraindicated in
    a. Antrochoanal polyp
    b. In polypoid mucosa covering the turbinates
    c. In grossly deviated septum where access to polyps is limited
    d. In cases where there is a possibility of spread of disease into surrounding anatomical structures such as orbit, indicated by CT scan
    e. Gross disease obscuring landmarks

3. Laser systems with negative feedback control
    a. Has an audible warning system when the beam is close to vital structures
    b. Has an audible warning system if the tissues are heated excessively
    c. Has a feedback system which reduces the energy output if the tissues glow due to excessive heating
    d. Cuts off the electric power supply in case there is ignition and fire
    e. Is an advanced scanning system which scans the target and delivers pre-determined energy adequate to remove the target tissue, as in laser stapes surgery

4. Given the following considerations, a suitable laser for nasal surgery is
    a. The CO_2 laser because of its shallow depth of penetration
    b. The Nd:YAG laser because it is fibre transmissible
    c. The Nd:YAG laser because it has a useful scatter within the tissue when used in non-contact mode, thus ablating the tissue beyond visibility, and ensuring total removal of polyp
    d. The Nd:YAG laser in contact mode which ensures minimum soiling of the lens of endoscope, reducing operating time.
    e. The Ho:YAG laser in near contact mode which ensures minimum soiling of the lens of endoscope

5. An all inclusive single instrument incorporating suction and fibre channel
    a. Has an advantage of providing continuous visibility of the target since the smoke is removed as it is produced
    b. Provides an excellent overall view of not only the polyp but also its relationship with other normal anatomical structures.
    c. Can easily be directed laterally even in cases of restricted access
    d. Has a disadvantage in that it cannot provide the overall view of the nasal anatomy while laser is being used since the tip of the laser fibre has to be in close vicinity of the target tissue
    e. Has a lever mechanism which can deflect the tip from -5 to 45 degrees from its axis

6. A semi rigid applicator for delivery of the fibre to the target with an adjustable tip
    a. Has an advantage of being able to be bent up to 180 degrees
    b. Can take large 600 um fibre and still have enough area for smoke removal

   c. Should not be used to bend thick, *e.g.* 800 um rigid fibre since it may fracture
   d. Allows a 200 um fibre to be bent adequately and still provide enough energy for the ablation of polyps
   e. All of the above

7. Laser usage in the management of nasal pathology has
   a. A limited application in selected cases
   b. Has cost implications due to capital outlay and single use fibre in some lasers
   c. A role to play in ambulatory surgery under topical anaesthesia
   d. Minimum bleeding and postoperative crusting.
   e. All of the above

Chapter 26

Transantral laser surgery and balloon dilatation

V. Kizhner and J. Krespi

1. Introduction

Transantral surgery and balloon dilatation (TASBD) of the sinus ostia or sinus outflow tracts is a mucosa-sparing technique, approved by the US Food and Drug Administration in 2005 (Stewart and Vaughan, 2010). The technique is similar to the dilating catheters used in other specialties to relieve obstruction. It is a minimally invasive surgical procedure for the management of failed Chronic rhinosinusitis patients (CRS). It may be performed either under general anaesthesia or in an office based setting. It spares the patient a full endoscopic sinus surgery (ESS) where the disease is minimal or moderate. It avoids nasal packing and thus reduces patient morbidity.

The technique involves displacing the obstructing pathology by passing balloon catheter and inflating it. The inflated balloon causes tissue displacement, restoring the patency of the ostium. It also creating micro-fractures of the bone surrounding the ostium and thus enlarges its diameter, in the same way as middle meatus antrostomy undertaken with cold instruments. Since the mucosa does not suffer surgical damage, the tract for sinus outflow is preserved. In moderate cases, the procedure can be combined with the standard ESS.

The enlarged osteo-meatal complex is both therapeutic and diagnostic, since it provides an unobstructed visualization of the ostium.

2. Instrumentation

FinESS Sinus Treatment is marketed by Entellus Medical, Maple Grove, MN. It consists of the access sheath with outer diameter of 3.7 mm, a 3.2 mm micro trocar and a 3 mm endoscope with 0° viewing angle. The working channel has 1.75 mm internal diameter. The balloon dilatation catheter is five mm wide and 18 mm long. It is connected to a light source and a camera. The trocar is used to make a puncture in the canine fossa, and the sheathe is passed in to the antrum. The endoscope is advanced to locate the pathology under video control. The balloon catheter, or laser fibre or any other suitable surgical instrument is passed through the working channel and the intended procedure is carried out under video control.

TASBD promises to be a safe technique performed for mild to moderate disease of the maxillary sinus or ethmoid infundibulum, sparing intranasal structures and mucosa (Stankiewicz *et al*., 2009). Patency using balloon dilatation for frontal sinusotomies has been shown to last at least 12 months (Kuhn *et al*., 2008). Addition of laser enhances the technique by providing a virtually bloodless surgical field.

3. Indications

3.1. Osteomeatal complex disease

In a limited and minimal disease obstructing the ostium of the maxillary sinus and the ethmoid infun-

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dibulum, the *transantral* approach provides a better visualisation, compared to a limited or partial view obtained in a conventional *trans-nasal* approach.

3.2. The posterior ethmoid disease

The posterior ethmoid cells drain into the superior meatus and their anterior extent is marked by the ground lamella of the middle turbinate. Intranasally, due to sloping skull base, penetration of the skull base at the level of the posterior ethmoids is potentially more prone to occur than at the level of the anterior ethmoids. Additional care must be taken of the posterior ethmoid artery traversing across the roof of the posterior ethmoid cells, which if injured can cause significant bleeding (Myers *et al*., 2008). Due to these factors, Wigand (2008), considered it inappropriate to undertake posterior ethmoid surgery as an isolated endoscopic procedure. It is not surprising that the posterior ethmoid cells may be the cause for up to 41% of FESS revisions (Musy and Kountakis, 2004).

A new elaborated technique of a *double* transantral puncture and two sheaths inserted through trans-canine fossa approach allows treatment of antral disease, and also provides a viable option of approaching the posterior ethmoids for transantral posterior ethmoidectomy.

4. Lasers

Haemostatic property of lasers is most useful during Transantral laser surgery with balloon dilatation (TLSBD), and /or posterior ethmoidectomy, The view of the target seen through a 2.7 mm FinEES endoscope is thus unimpeded.

Only flexible fibre transmissible lasers are suitable, The common laser in use are the diode, CO_2 and Holmium-YAG lasers. The authors chose to omit the CO_2 due to high cost of the flexible fibre.

The diode and the Holmium:Yag lasers have *reusable* flexible fibres and are thus cost effective. The near infrared (NIR) 980 nm diode is used at a setting of 10W with a flexible 300 micron fibre. The 20 W Holmium:Yag (VersaPulse PowerSuite, Lumenis, Santa Clara CA) is set at five Hz, five W with a 350 or 550 micron fibre.

It is also convenient to use laser should any additional concomitant procedure such as submucous resection or reduction of turbinate deemed necessary. Smoke evacuation was possible largely due to the dilated ostium with the suction in the nasal cavity or in the proximity of the second canine fossa port. As the endoscope can be inserted in either ports, all surfaces apart from the frontal wall are accessible to surgery. The laser is used for several purposes: tissue vaporisation in the antrum, coagulation of mucosa and control of minor bleeding in the antrum. The laser is also used to open the posterior antral table to gain access to the posterior ethmoids.

5. Method

Thirty five patients in whom the medical management had failed, were treated with TLSBD. The anatomy of the antrum is fairly constant with the ostium located medial to the medial ridge on the medial wall (Fig. 1). Initially a single trocar is inserted through canine fossa and the maxillary cavity inspected. The first puncture is performed at the crossing of a line dropped vertically downward from the pupil and a transverse line passing through the maxillary floor (Robinson *et al*., 2005). The second puncture is performed lateral and higher to the previous one. Any dental injury is unlikely since the canine fossa does not contain dental roots.

In the presence of maxillary pathology such as cyst or polyp, it may not be possible to access the ostium for transantral balloon dilatation. In such cases, a second puncture is performed and the sheath is inserted. The two sheaths enter with a different angulation to facilitate instrumentation under endoscopic control (Fig.1). A double puncture access is also necessary for procedures on posterior ethmoids.

The modification from a single port approach to a double port approach allows the use of the working channel for introduction of various tools (such as paediatric instruments for FESS, laser fibres, microdebrider) inside the maxillary sinus. After treating the maxillary sinus pathology the balloon is inserted through the maxillary ostium and inflated.

Location of the posterior ethmoids is at the most supero-medial corner of the antrum lateral to the ostium. Its thin bony lamina can be easily identified under direct vision (Langenbrunner and Nigri, 1977). After localisation and penetration of the posterior ethmoids, additional bone is removed and any diseased tissue is removed with suction or debrided. Drainage of the posterior ethmoids in to the antrum is achieved. The anterior ethmoids can also be opened by continuous exanteration in a medial-anterior direction.

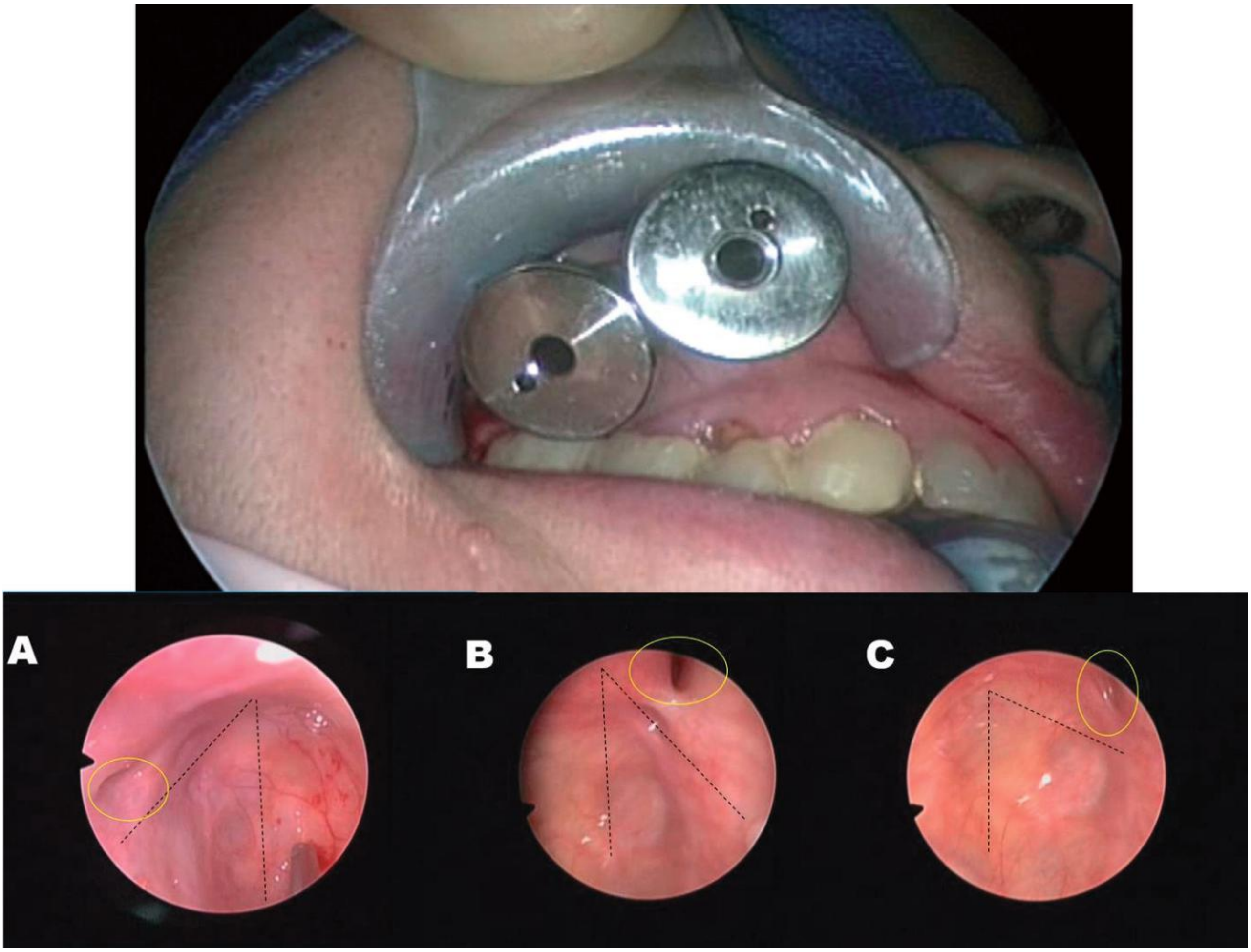

Fig. 1. Two working ports through canine fossa with different angulations (note small slit in sheath) with antral anatomy delineating location of the posterior ethmoids relative to the maxillary ostium.

6. Surgical outcome

Lund-Mackay score (LMS) and SNOT20 scores before surgery and at one month follow up were recorded. Patient demographics, intranasal endoscopic findings, intra-operative findings and post-operative complications were collected.

Twenty-five patients who had only transantral laser surgery with balloon dilatation (TLSBD), and ten who had TLSBD as well as posterior ethmoidectomy were reviewed. Patients included 19 females and 16 males with ages ranging 11-67 years. The procedure was undertaken either under general anaesthesia (n = 33) or under local infiltration with sedation (n = 2).

One patient had revision surgery. Four patients had severe polyposis. Two patients who were planned for TLSBD had to be converted to standard endoscopic sinus surgery due to extensive disease. Overall 64 maxillary sinus ostia were dilated with the FinESS procedure. Six patients had intra-maxillary cyst (MC) near the ostio-meatal unit, partially obstructing the ostio-meatal unit (Fig. 2). The cysts were ablated or marsupilised with a 980 nm near-infrared diode laser using five W in continuous mode delivered via a 300μ flexible fibre navigated with fibre manipulator (Fig. 2). In some patients, the Holmium laser was similarly used with a setting of five Hz, five W. The effect on antral wall following laser vaporisation and suctioning of polypoid tissue from the posterior ethmoid is seen in Figure 3. Polypoid disease encountered in five additional patients was approached with a microdebrider or laser.

Ten transantral posterior ethmoidectomies were performed. During the operation, polypoid mucosa or thick secretions were removed from the posterior ethmoids. There were no intracranial or intraorbital complications in any patients. Several posterior ethmoidectomy procedures were performed with fibre

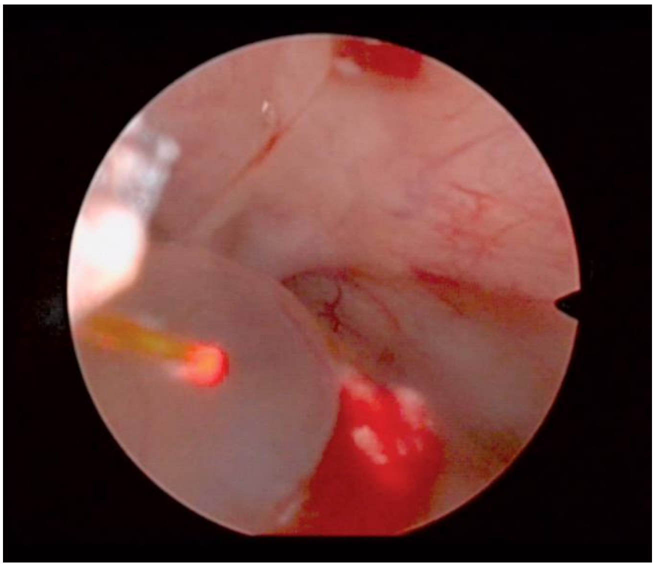

Fig. 2. Obstructing OMC cyst with laser fibre.

manipulator. As the middle turbinate and anterior ethmoids were intact, no packing, post-operative debridement or cleaning was needed. Two patients had a mild facial swelling which subsided by third day. Two patients had transient dysesthesia over the upper lip lasting one week. There were no dental or wound complication.

The average preoperative LMS was 6.4 (0.03 CI95%). SNOT20 scores comparison using a two-tailed T-test decreased from 1.77 to 0.83 ($P < 0.05$).

Cultures were obtained from the ostio-meatal unit during surgery under sterile conditions. Maxillary sinus cultures were sterile in most patients, however, three were positive for H. influenza, S. pneumonia, and S. epidermis. Time off work after TLSBD using single or double puncture was no more than three days. On the other hand, where standard endoscopic sinus surgery was carried out, the recovery was longer. No postoperative nasal packing was used and minimal crusting was observed. Only a single trans-nasal post-operative debridement visit was necessary.

7. Discussion

TLSBD resulted in a significant improvement in SNOT scores with low morbidity. It is possible to treat most antral pathology through the dual pucture canine fossa approach. Since it is possible to tackle mild or moderate disease with the dual approach using FinESS treatment, most patients had a less severe side treated with this approach.

The only current limitation is the size of the working channels of the FinESS endoscope. The instrumentation is therefore restricted to the available paediatric or fine otologic instruments inserted through the second sheath.

Side effect, *i.e.*, transient dysesthesia, was minimal, lasting no more than a week. There was no incidence of dysesthesia of teeth. Work productivity loss was maximum three days. Repeated post-operative

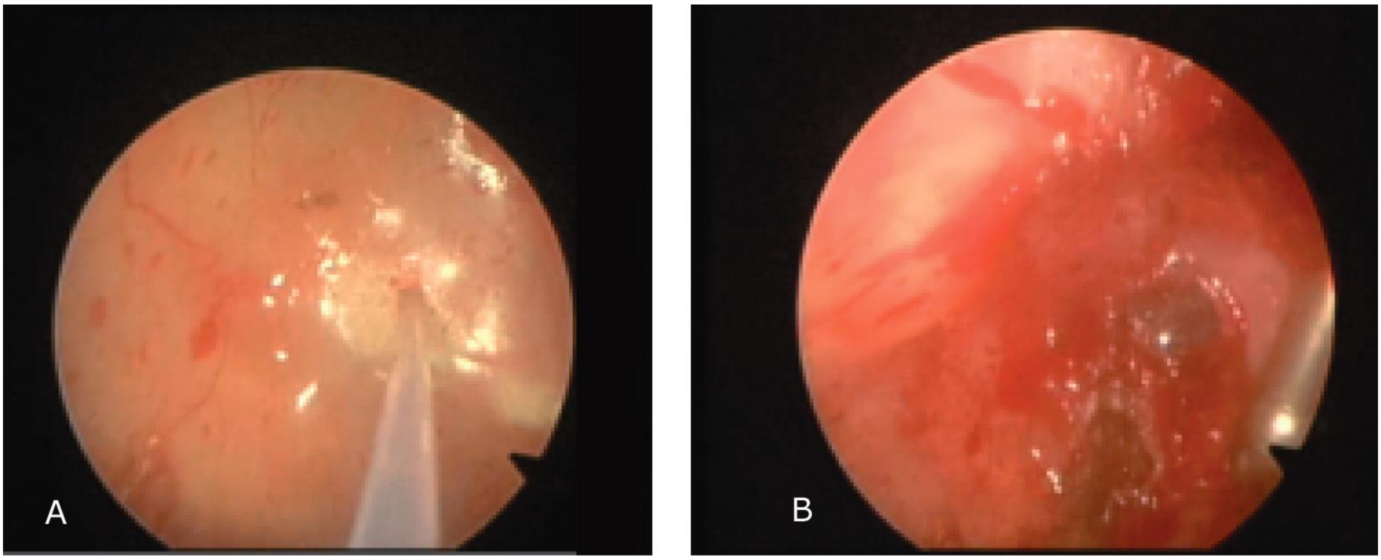

Fig. 3. Left corner: Holmium laser effect on posterior antral wall; Right posterior ethmoids exenterated to the antrum after laser coagulation and bony vaporisation followed by removal of thick polypoid secretion.

debridement was not necessary. The recovery was quick, without need for packing, thus significantly contributing to patient satisfaction (Friedman *et al.*, 2008).

While Harar proposed a higher incidence of LMS and CRS in patients with maxillary cysts (MC) (Harar *et al.*, 20007), others showed no correlation between LMS and MC (Kanagalingam *et al.*, 2009). Contrary to prior publications indicating that MC do not represent any additional manifestation to CRS, 25% of our patients had MC that obstructed the ostium and were successfully treated with TLSBD through one or two ports via the canine fossa.

We believe that dual puncture approach overcomes the only limitation for FinESS TLSBD, extending its application to a more extensive disease than just mild maxillary and ethmoid disease. It also offers a transantral access to posterior ethmoids, limited surgery of the pterygopalatine fossa, orbital floor surgery and trauma repair. The second working channel allows manipulation of additional instruments, such as the introduction of laser fibres, microdebrider, therapeutic irrigations and obtaining direct cultures. With access sheaths as wide as three mm, most pediatric endoscopic sinus surgery equipment can be utilised inside the sinus making a broader FinESS approach potentially applied to patients with polyps, cysts and fungal disease.

Transantral posterior ethmoidectomy is not a new approach. It has been performed prior to and during the FESS era (Kimmelman *et al.*, 1988). The current transantral approach is performed for orbital decompression, tumours or skull base surgery. However, employing transantral posterior ethmoidectomy may prove advantageous even for simpler tasks. It has been shown that the posterior ethmoids may be the source for polypoid disease (Andrews *et al.*, 2005). Since CRS is unlikely to be present in just the posterior ethmoid disease without the anterior ethmoid disease, it seems prudent to exenterate isolated opacified posterior ethmoids seen on a CT scan. In our series both isolated posterior ethmoid disease cases proved to have polypoid mucosa. Transantral posterior ethmoidectomy thus offers an additional benefit to the patient and visits for post-operative debridement are spared. It is assumed that the efficient maxillary ciliary action will be able to clear the additional drainage of the posterior ethmoids, however, only a CT scan can ascertain if the disease in the posterior ethmoid has recurred, due to failure to inefficient drainage.

Transantral posterior ethmoidectomy is beneficial in *revision* FESS particularly when familiar landmarks are missing. Occasionally FESS performed even under navigation precludes a total ethmoidectomy, selected *transantral* posterior ethmoidectomy may be a solution for those cases, especially with a laterally placed posterior ethmoids cell (Rawlings and Han, 2010). Contrary to revision FESS where appreciation of the usual landmarks may be challenging, the posterior antral wall is immediately noted. However, when a spenoidotomy or fronto-ethmoidectomy or a high ethmoid surgery for drainage is required a standard approach is more suitable. Balloon dilatation of sinuses is applicable to all sinuses except the posterior ethmoids. However, even in cases which are limited to the pathology of only posterior ethmoids, concomitant balloon dilatation can be beneficial.

The addition of a laser is most useful, given the narrow confines of the sheath and the working channel of the endoscope. With a paediatric endoscope and a single additional working port, the laser can marsupilise cysts, debride mild to moderate polypoid disease and assist in opening the posterior ethmoids. Moreover, it is possible to use the laser in associated nasal pathology such as SMR and or turbinate reduction, without additional need for packing.

Therefore we conclude that the following indications are most amenable to transantral posterior ethmoidectomy:

- Isolated posterior ethmoids disease;
- Posterior ethmoids disease with mild anterior ethmoid disease amenable to balloon sinuplasty;
- A lateral posterior ethmoids cell;
- Revision FESS with posterior ethmoids disease particularly when the middle turbinate has been resected at previous surgery;
- Where patient compliance for future appointments for debridement is lacking;
- Patient unwilling to have septoplasty for FESS facilitation.

The contraindications are:

- Hypoplastic maxillary sinus, significant maxillary disease;
- Orbital exophthalmos;
- Moderate to severe antral or anterior ethmoid disease;
- Children without completely erupted canine teeth.

8. Conclusion

A dual puncture of the canine fossa is a suitable solution when TLSBD attempt fails with a single port due to maxillary disease. This approach also allows posterior ethmoidectomy thus expanding the indications beyond balloon sinuplasty and occasionally avoiding endoscopic sinus surgery while maximising patient satisfaction. The addition of a laser can help overcome technical difficulties in areas where tissue destruction needs to be as bloodless as possible.

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MCQ – 26. Transantral laser surgery and balloon dilatation

1. Trans-antral balloon dilatation of the sinus ostia
    a. Is a minimally invasive procedure
    b. Provides a mucosa sparing technique to drain the sinus via natural ostium
    c. Result in a permanent patency of the ostium
    d. Can be performed under local anaesthesia
    e. May result in bleeding which requires packing

2. Trans-antral approach involves
    a. A Caldwell Luc procedure to open the sinus to visualise the ostium for balloon dilatation
    b. Making a puncture in the canine fossa with a trocar
    c. The site of the puncture located just medial to the canine tooth
    d. A second puncture, if required, located higher and medial to the first puncture in order to avoid injury to the root of the canine tooth
    e. A puncture in the canine fossa, which may result in damage to braches of the infraorbital nerve

3. Laser is used
    a. For vaporising the bone of the around the ostium to enlarge it
    b. For tissue vaporisation in the antrum,
    c. For coagulation of mucosa
    d. To gain access to the posterior ethmoids
    e. All of the above

4. The most suitable laser is
    a. The CO_2 laser, since it is well absorbed by the water content of the mucosa
    b. The HO:YAG laser, since it has adequate haemostatic property
    c. The diode laser, since it is portable and maintenance free
    d. The KTP laser, since it is absorbed by blood pigment and gives bloodless field
    e. None of the above

5. The choice of the laser depends upon
    a. Its availability
    b. Its delivery via an optical fibre or a waveguide
    c. The cost of the fibre or waveguide delivery
    d. Minimum collateral damage to avoid stenosis of the ostium due to scarring
    e. All of the above

6. For trans-antral posterior ethmoidectomy, location of the posterior ethmoids is
    a. At the most supero-medial corner of the antrum lateral to the ostium.
    b. At the most supero-lateral corner of the antrum lateral to the ostium
    c. Is obstructed if antral pathology such as a polyp is present
    d. Is visualised by the use of two portals by performing double puncture
    e. Not possible via trans-antral route

7. If during balloon sinuplasty the bleeding is excessive, it should be controlled by
    a. Diathermy
    b. Continuous delivery of the laser energy to the bleeding area until the bleeding stops
    c. Withdrawing the fibre and striking the bleeder with defocused beam

   d. By packing the nose temporarily with ribbon gauze soaked in decongestant
   e. All of the above

8. Balloon sinuplasty is not suitable
   a. For hypoplastic maxillary sinus
   b. For frontal sinus disease
   c. For sphenoidectomy
   d. For fungal sinusitis
   e. For chronic sinusitis resilient to antibiotic therapy

9. Balloon sinuplasty is a minimally invasive procedure for
   a. Failed chronic rhinosinusitis patients
   b. Isolated posterior ethmoids disease
   c. Posterior ethmoids disease associated with mild anterior ethmoids disease
   d. Patient unwilling to have septoplasty for FESS facilitation.
   e. All of the above

Chapter 27

CO_2 laser management of rhinophyma

S. Jovanovic

1. Introduction

Rhinophyma has been observed in Greece since ancient times, but was first mentioned by the Viennese dermatologist Ferdinand von Hebra in 1845. The term rhinophyma (rhis: Greek for nose; phyyma: Greek for growth) was coined by him in 1856 (Von Hebra, 1856) after he had first described the disease as third degree acne rosacea (Von Hebra, 1845). Hypertrophy of the nose occurs almost exclusively in males, and results from massive hyperplasia of the sebaceous glands with diffuse fibrosis and increased vascularity. It develops in 7-10% of patients with rosacea, a type of inflammatory midfacial dermatosis.

2. Aetiology

Rhinophyma is a benign lesion and does not affect the airway. The cause of rhinophyma is unknown. Heavy alcohol consumption was once thought to be the aetiological factor. However, this is no longer considered to be of any significance since rhinophyma occurs equally in those who do not drink at all. Most patients complain of cosmetic disfigurement. However, it may also cause emotional distress if obvious or extensive. On examination, the nose is large, bulbous, and ruddy.

3. Management of rhinophyma

The medical management of rhinophyma is restricted to the earlier stages of acne. Once formed, rhinophyma requires surgery. Surgical management in the form of dermabrasion and dermaplaning with rotating instruments is depicted in copperplate engravings dating back to the 16th century. In modern times, the first surgical treatment was described by Dieffenbach in 1845 and consisted of excision of a vertical and a horizontal skin area and approximation of wound margins. Berson introduced a modified treatment in 1848, which was published by Weinlechner in 1901 (Joseph, 1931). This involved the subcutaneous ablation of hyperplastic layers of tissue. However, the method was quickly abandoned because of unsatisfactory cosmetic results.

The current standard method for the management of rhinophyma consists of its removal with rapidly rotating instruments, such as wire brushes and fraises. There is considerable intraoperative bleeding, and preservation of deep layers, essential for skin generation, is sometimes difficult. Loss of the deeper layers for skin generation leads to unsightly scarring, particularly at the tip of the nose.

A monopolar or bipolar electroknife provides a relatively bloodless field, but, as with cold instruments, the depth of ablation is difficult to control. There is a risk of not only destroying the deep layers for skin generation, but there is the added risk of damage to the cartilaginous framework of the nose.

The ultra-high frequency radiowave scalpel has been used for the excision of rhynophyma. This scalpel produces precise excision with minimum scarring (Botero, 1996). Although easy to handle and inexpensive, this technique is not yet widely used. Further reports to assess its efficacy are necessary.

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A number of workers report on using the CO_2 laser. This treatment is undertaken under local anaesthesia as an outpatient procedure. In the following sections, the present author describes his experience with the CO_2 laser in the management of this condition.

4. The CO_2 laser

The CO_2 laser has a high absorption coefficient in water. Most of the energy is absorbed at the surface, with instant ablation of the tissue. Wound healing occurs with minimum scarring since the coagulation zone is shallow (Walsh and Deutsch, 1988).

The unwanted effects of carbonisation and coagulation can be further minimised (Hobbs *et al.*, 1987; Grevelink and Brennick, 1994) with the use of scanner systems such as AcuPulse 40ST. These scanners provide micro-processor-controlled movement of the focused laser beam over a predetermined area by rotating mirrors. Therefore, ablation is precise with minimal thermal effects (Waldorf *et al.*, 1995). The CO_2 laser with the scanner system is suitable for skin resurfacing in the management of atrophic, hypertrophic, or common acne scars, and perioral wrinkles, periorbital crow's feet, and rhinophyma (Sedlmaier *et al.*, 1997).

5. Anaesthesia in rhinophyma surgery

The procedure can be adequately carried out under local anaesthesia. One percent Xylocaine with adrenaline in a 1:200,000 concentration is injected in order to block the infraorbital nerve and branches of the supratrochlear and supraorbital nerves. Each vestibule is infiltrated in the intercartilaginous area. Tampons are loosely inserted into each vestibule.

6. Equipment

For laser ablation of rhinophyma, two CO_2 laser systems are suitable: a 20C CO_2 laser with a non-synchronised SilkTouch™ scanner and a 40C system with a computerised scanner system (AcuPulse 40ST, Fig. 1).

Fig. 1. AcuPulse 40ST.

With the non-synchronised SilkTouch™ scanner system, a 200-mm handpiece is used. For ablation of the superficial layers, a scanned area of 4-6 mm is selected and the power is set at 10 W. Ablation near the cartilaginous areas is carried out with a power of 8-10 W, but the exposure time is reduced to single shots of 0.2 seconds' duration.

With computerised laser systems, the so-called paintbrush mode are available. The microprocessor-controlled rotating mirrors are synchronised to the laser, so that the movement of the laser beam always starts at the same point when the laser pulse begins. Thus, ablation is even more controlled, reproducible, and homogeneous. A 200-mm handpiece includes an integrated suction channel (Fig. 2). For ablation of the superficial layers, the paintbrush mode is selected and the handpiece is moved smoothly over the surface of the rhinophyma. A large volume of tissue can be ablated quickly with a setting of 18 W in the continuous mode, and a scanned area of 5 mm in diameter. As the cartilage is approached, single shots of 0.45 seconds' duration are used.

In the FeatherTouch mode, the laser is set at a power of 36 W, with an exposure time of 0.11 seconds and a scan area of 8 mm.

The SilkTouch mode has an ablation depth of approximately 80 µm. The FeatherTouch mode provides an even shallower ablation of approximately 40 µm. The laser plume is removed by a dedicated suction device in order to minimise the theatre pollution (*e.g.*, Xplume, ESC-Sharplan Co., Tel Aviv, Israel).

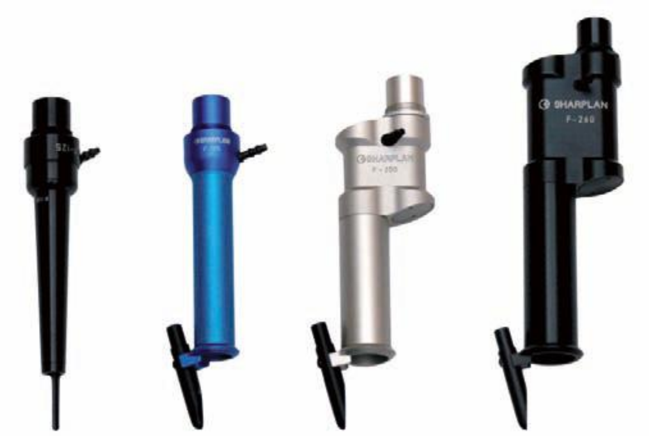

Fig. 2. A range of handpieces for the treatment of skin with the CO_2 laser.

7. Surgical technique

In the author's department, 30 patients have been treated with the CO_2 laser and scanner systems under local anaesthesia since 1996. The first five patients were treated with the non-synchronised SilkTouch scanner. Since the introduction of the new scanner system, a further 25 patients have been treated.

The surgical technique for ablating rhinophyma is similar to the skin resurfacing technique (Fig. 3A). However, there are two crucial differences. In rhinophyma, the volume of tissue for ablation is much larger, and furthermore, the base of the operating field contains cartilage of the nasal framework, and extra care is needed as the operation approaches the cartilage.

When available, the paintbrush mode is used for ablation of larger volumes of tissue. The handpiece is moved in a sweeping manner over the tissue, so that it is rapidly ablated in sheets of thin layers, rather than in thick slices. The movement of the handpiece should be rapid, smooth and even in order to avoid undulations. The contours of the nose are gradually restored by 'wall-to-wall' reduction of the tissue using sweeping strokes, not unlike those of a painter. In the vicinity of the cartilaginous nasal skeleton, single pulses in the SilkTouch or FeatherTouch mode should be applied. Here, the ablation depth should be reduced in order to avoid scar formation and deformity. It is not advisable to undertake excessive ablation as this may lead to ugly scarring. It is better to carry out a repeat procedure, if necessary.

Frequent cleansing of the wound with wet swabs is necessary in order to maintain the surgical progress (Fig. 3B). If the carbonised layer is not removed, it will absorb most of the energy and slow down the surgical progress. Worse still, a heated carbonised layer increases the temperature of the tissue to 300-400°C. The heat spreads deep into the tissue and increases the thermal damage zone, which is precisely what needs to be avoided.

7.1. *Intraoperative haemostasis*

CO_2 laser irradiation seals the cutaneous capillaries and is usually sufficient for intraoperative haemostasis. Bipolar coagulation may occasionally be necessary to control bleeding from larger vessels.

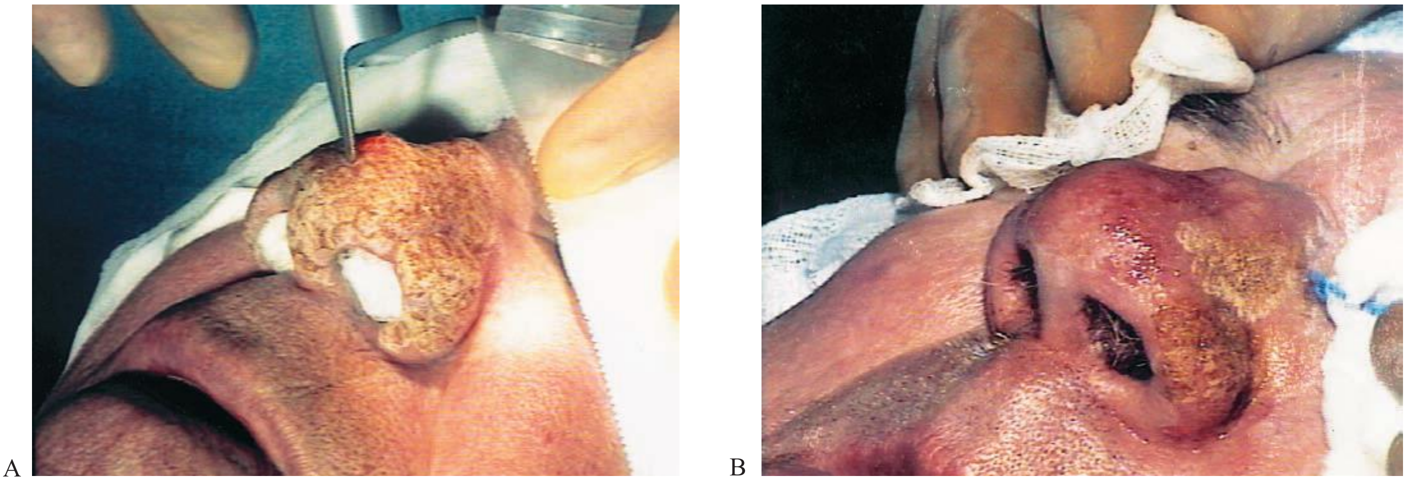

Fig. 3. Surgical technique for ablating rhinophyma is similar to skin resurfacing (A), frequent cleansing with wet swab is necessary to remove charred tissue (B).

8. Postoperative care

Postoperatively, crusting is minimised by the topical application of a thick layer of vaseline. This application is continued for a period of two to three weeks until re-epithelialisation is complete. Acyclovir (1 × 400 mg orally) is prescribed one day preoperatively and continued for a further seven days. Erythromycin (333 mg orally, three times a day) is also prescribed in order to prevent bacterial infection. The patient is asked to avoid exposure to direct sunlight for a good six months.

Some authors recommend different postoperative treatment regimens with cortisone-containing creams (Christopher *et al*., 1995; Abergel and Dahlman, 1995; Fitzpatrick, 1995). The present author recommends local steroid application after complete re-epithelialisation to reduce the duration of erythema. Hyperpigmentation of the reepithelialised skin is prevented by the application of a sun cream with a high shielding factor for UVA and UVB radiation.

9. Patient benefit and risk

Local anaesthesia provides adequate analgesia for the procedure to be carried out painlessly and without much discomfort. Intra- or postoperative bleeding is unusual. Likewise, there does not seem to be any postoperative incidence of herpes simplex or prolonged bacterial infection. With the CO_2 laser scanner, scar formation is negligible and of little importance. The laser parameters and the application technique described above have proved successful in the present author's hands. However, the operator should assess the performance of the equipment, and use suitable parameters to minimise scarring. Erythema is a prominent postoperative feature and persists for up to three months postoperatively. It is wise to warn the patient accordingly.

10. Surgical outcome

Both systems performed well and neither had any particular advantages for adequate surgical outcome. The aesthetic surgical results were very satisfactory in all cases. Re-epithelialisation was usually complete within three weeks. Figures 4A, B, C show a patient treated with the SurgiTouch™ system which is now replaced with AcuPulse ST40.

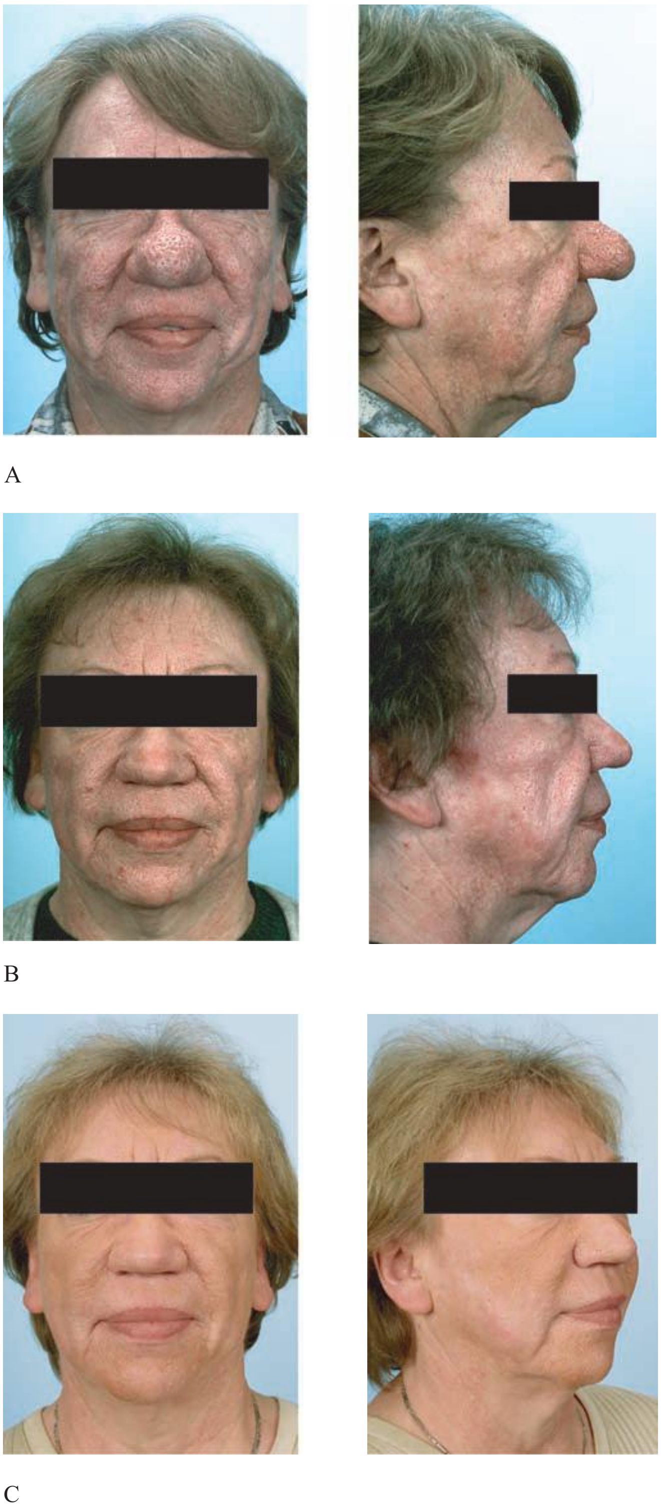

Fig. 4. Frontal and lateral view of a patient with acne vulgaris and rhinophyma: A: preoperatively; B: eight weeks postoperatively; C: one year postoperatively.

11. Is CO_2 laser a gold standard for surgery of rhinophyma?

As long ago as 1988, Bohigian *et al.* (1988) used the CO_2 laser for the management of rhinophyma. However, the technology available at that time caused carbonisation of the treated surfaces.

The thermal energy of the CO_2 laser acts like a hot scalpel. In the continuous-wave mode, it exhibits characteristics which are very suitable for ablation of the large volume of tissue encountered in rhinophyma. However, it is necessary to appreciate the tissue interaction with the laser energy in order to achieve a good postoperative result.

When the laser is used in the continuous-wave mode, the temperature of the tissue continues to rise throughout the exposure time. The tissues are said to be thermally active during the exposure, and the energy is conducted into the deeper tissue. When the exposure is stopped, the tissue returns to its ambient temperature. The time taken to return to the ambient temperature is known as the thermal relaxation time. If the thermal conduction time equals the thermal relaxation time, the thermal damage zone is minimal. The relaxation time varies from tissue to tissue and also from wavelength to wavelength.

If the exposure time approaches the thermal relaxation time or is even shorter, tissue such as the cutis can be ablated with almost no thermal side effects. With the use of a scanner system, the thermal damage zone can be reduced dramatically by reducing the exposure time to < 10 msec. Thus, the microchip-controlled rotation of mirrors in the scanner systems has proved to be a major advance in the management of rhinophyma (Hobbs *et al.*, 1987; Grevelink and Brennick, 1994; Jovanovic and Sedlmaier, 1998).

One advantage of the SilkTouch™ scanner is that it can be connected to the CO_2 lasers currently in use. Depending on the range of indications, the application system coupled to various handpieces can trace diverse scanning patterns of varying diameters (1-9 mm), which the laser beam covers in a predetermined exposure time (*e.g.*, 100 or 200 msec). The thickness of the ablated layer is controlled by the power setting (Jovanovic and Sedlmaier, 1998).

The synchronised, microprocessor-controlled rotating mirrors from the newest generation of scanner systems ensure that the movement of the laser beam always starts at the same point when the laser pulse begins. Thus, the ablation is even more controlled and smooth.

Carbon dioxide laser management, particularly with the scanning accessory, remains the method of choice. Lim *et al.* (2009) treated nine consecutive patients with moderate and major rhinophyma with scanned carbon dioxide laser with excellent cosmetic results and no major postoperative complications or recurrence of the condition. In their opinion, scanned carbon dioxide laser is safe and highly effective treatment for rhinophyma.

In order to assess the long-term effectiveness in the management of rhinophyma with CO_2 laser, Madan *et al.* (2009) reviewed the outcome of 124 patients treated with the CO_2 laser between 1996 and 2008. Depending on the severity of the condition, the CO_2 laser was used in resurfacing mode (Silk Touch scanner; Sharplan, 4-7-mm spot at 20-40 W) to debulk the larger rhinophymas, or in continuous mode (10-20 W using a defocused 2-3-mm beam) to reshape the nasal contours. Laser treatment was completed in a single session in 115 of 124 patients. All patients were sent a satisfaction questionnaire in 2008. Of the 52 respondents, all reported high levels of satisfaction following treatment. Improvement, noted at the first post-treatment review at three months, was maintained long term. The main untoward effect was pain associated with injection of local anaesthetic. There was also scarring and hypopigmentation in four patients and open pores in two patients. They concluded that the CO_2 laser is an effective and durable treatment for rhinophyma. Treatment carries a low risk of side-effects and is associated with high patient acceptability and satisfaction.

12. Alternative surgical methods for rhinophyma

While CO_2 laser remains method of choice in the surgical management of rhinophyma, in some cases, there is scarring and hypopigmentation. Scarring is thought to be due to collateral damage to the cartilaginous structures, but there is no conclusive evidence. In any case, careful attention to setting parameters and surgical laser skill is what decides the surgical outcome. And this is also true with every other modality used in the surgical management of this condition.

12.1. Conventional dermabrasion

The depth of conventional dermabrasion is likewise associated with poor reproducibility, since it depends on the manual skill of the individual surgeon. Cold instrumentation inevitably results in continuous bleeding, which needs to be controlled, thus hampering progress and lacking precision.

12.2. Mono- or bipolar electroknife

An alternative method for the management of rhinophyma is advocated by Gjuric and Rettinger (1993), who used a mono- or bipolar electroknife. By means of this method, ablation of the hyperplastic tissue is relatively quick, but neither the depth of penetration nor the thermal effect are precisely controllable. Thus, there is a potential for postoperative scarring, especially in the alar or tip regions.

12.3. Combined carbon dioxide laser and bipolar electrocoagulation

Cravo *et al.* (2009) used a combination of carbon dioxide laser and bipolar electrocoagulation to treat four male patients with moderate-severe rhinophyma. All patients achieved marked cosmetic results with minimal scarring. They concluded that the combined method provided a bloodless operative field which allowed the sculpting of the hypertrophic areas, leading to a good cosmetic outcome and a *pain-free* postoperative recovery.

12.3.1. Comparison of CO_2 laser and electrosurgery in the treatment of rhinophyma

Greenbaum *et al.* (1988) carried out a controlled study to compare the efficacy of the laser and the electrocautery in three patients with rhinophyma. One half of the rhinophyma was treated with the CO_2 laser and the other half, with electrocautery. There was no significant difference in the outcome with either modality.

12.4. Carbon dioxide laser and pulse dye laser (PDL)

Following a successful treatment of rhynophyma with CO_2 in a 63-year-old man, Moreira *et al.* (2010) used pulse dye laser for post-treatment purpura with a satisfactory cosmetic result.

12.5. The ultrasonic scalpel

Metternich *et al.* (2003) maintained that, because of the exceptional vascularity of the rhinophyma, there is a persistent intraoperative bleeding during traditional surgical approaches. Control of bleeding with electrocautery or laser invariably damages cartilage by thermal injury.

The ultrasonic scalpel (UltraCision Harmonic Scalpel) offers two advantages. Intra-operative haemostasis is excellent to the extent that no additional measure to control the bleeding was necessary. There is also a very welcome advantage of the tactile feedback which adds to the accuracy of the procedure, enabling an accurate sculpting of the nose.

They used the UltraCision Harmonic Scalpel in six patients. Postoperative pain was minimal. Wound healing was uneventful in all cases. Postoperative re-epithelialisation occurred within 28 days. Delayed complications such as scarring did not occur within a median follow up of 13 months. Histopathological evaluation was possible in all cases. They concluded that the UltraCision Harmonic Scalpel offers a surgical treatment of rhinophyma with efficacious intra- and postoperative haemostasis.

12.6. The disposable razor

Those who do not have hi-tech equipment such as the laser or the radiofrequency, do not despair! Fishman *et al.* (2009) reported a simple, safe, effective and cost-effective technique for the surgical management of rhinophyma using a disposable razor blade! The blade is first sterilised with soaking in aqueous Betadine. Following cold-instrument excision, the disposable razor is used to finish off the procedure, thus providing a smooth postoperative surface.

13. Conclusion

The present author believes that the new mode of irradiation with rotating mirrors has extended the application of the CO_2 laser in an interesting direction for specialists working in the field of plastic, reconstructive head-and-neck surgery.

Thus, treatment with minimal thermal trauma can be undertaken for rhinophyma and other benign skin lesions, such as hypertrophied scars, scars after common acne, superficial periorbital xanthomas, benign neoplasm such as verruca vulgaris and seborrhoeic keratoses (Abergel and Dahlman, 1995). Another interesting indication is laser skin resurfacing for the smoothing of fine wrinkles (Ross *et al.*, 1995; Waldorf *et al.*, 1995; Sedlmaier *et al.*, 1997).

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MCQ – 27. CO_2 laser management of rhinophyma

1. CO_2 laser is suitable for rhinophyma surgery because
   a. Its use causes minimum hypopigmentation
   b. It is an excellent intraoperative haemostat
   c. It has a shallow depth of penetration
   d. It causes minimum scarring
   e. Its use assures a low rate of recurrence

2. CO_2 laser is used
   a. In continuous mode
   b. In superpulse mode
   c. In ultrapulse mode
   d. In scanner mode
   e. All of the above

3. CO_2 laser is used
   a. In focused mode
   b. In defocused mode
   c. In resurfacing mode
   d. With an optical fibre
   e. Coupled with microscope

4. Postoperative hyperpigmentation is treated with
   a. Further application of the CO_2 laser
   b. With pulse dye laser
   c. With KTP laser
   d. With conventional dermabrasion
   e. With photodynamic therapy (PDT)

Chapter 28

Laser management of recurrent epistaxis

J.U.G. Hopf, M. Hopf and H. Scherer

1. Introduction

The use of fibre-guided laser systems for the surgical management of recurrent nasal bleeding has become an internationally established method. For this purpose, a number of wavelengths have been used: the argon (Parkin *et al.*, 1981; 1985; Haye and Austad, 1991); KTP (Levine, 1989); and Nd:YAG, the most widely used laser in Germany (Illum and Bjerring, 1988; Dobrovic and Hosch, 1994; Werner, *et al.*, 1997a,b; 1999).

2. Laser wavelength

2.1. Argon laser

Due to high absorption by haemoglobin, the depth of penetration of the argon laser is minimal. In the 'no touch' or 'near-contact' modes, the authors routinely use the following argon laser parameters: power setting, 2-5 W; period of exposure, 0.02–0.1 sec; repetition rate, up to 6 Hz, for vascular mucosal lesions.

2.2. Nd:YAG and diode lasers

The Nd:YAG and diode lasers, in the 'no touch' mode, are also suitable therapeutic options for this indication. There are very few reports in the literature of the diode laser being used in the management of vascular disease and malformations of the vessels of nasal mucosa. Depending on the type of diode used, the wavelength emitted by this laser ranges from 810-980 nm. The depth of penetration ranges between the values of the argon and KTP lasers on the one hand, and the Nd:YAG on the other. Thus, the diode laser allows coagulation, not only of small lumen vessels located directly on the mucosal surface, but also of vessels in the subepithelial layers.

3. Indications for laser management of epistaxis

The coagulative effect of lasers can be used to stop a recurrent, circumscribed source of bleeding in the nasal cavity. The patients treated by the present authors suffered from 'recurrent epistaxis' of various aetiologies. Approximately one third of the patients presented with recurrent idiopathic nasal bleeding. The causes in a further third of the patients included telangiectatic, cavernous or pyogenic septal granuloma, capillary septal haemangioma, uni- or bilateral vascular ectasia in Kiesselbach's plexus (Fig. 1) and/or vascular convolution near the tip of the middle turbinate. In the remaining third, recurrent nasal bleeding was due to hereditary haemorrhagic telangiectasia (HHT), (Osler-Weber-Rendu disease). In HHT, or in systemic disorders resulting in nasal bleeding, the frequency and severity of bleeding may be reduced, but the effects of treatment are usually short-lived. The management of epistaxis in HHT is covered in Chapter 29.

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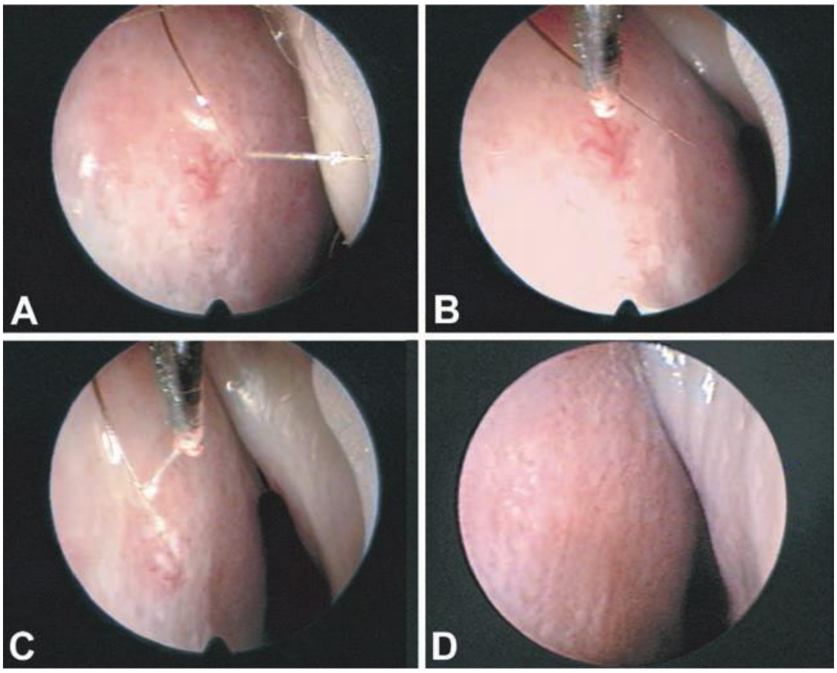

Fig. 1. Laser treatment of prominent vascular Little's area (A, B, C) during treatment and (D) 6 weeks postoperatively.

4. Laser management

A good endoscopic view and an enlarged view on the monitor allows the clear definition of bleeding points which may not be clearly visible to the naked eye. If the bleeders are situated in the anterior part of the nose, laser treatment is carried out with the bare fibre and a spot diameter of 0.5 mm. Management usually involves several sessions scheduled at intervals of four weeks.

For deeper lesions, a slim laser endoscope with a longitudinally oval cross-section (Storz, Tuttlingen, Germany) is useful. This endoscope has a channel for guiding laser fibres with an outer diameter of up to 1.1 mm. Fibres of 600 µm can pass through this channel with ease. The tip is advanced by about 3 mm beyond its exit from the fibre channel so that it is visible on the monitor.

The emerging beam is divergent, and the power density decreases as the distance between the fibre tip and the target is increased. The decreased energy results in coagulation of the lesion rather than vaporisation. The lesion is approached from the periphery, with the tip a few millimetres away from the target. As the mucosa blanches, the spot is moved towards the lesion, and the exposure continues on the target until it also blanches. By using the laser in the defocused mode, any popcorn effect (premature bursting of a blood vessel) is avoided.

5. Surgical technique

The present authors routinely carry out diode laser treatment (810 or 940 nm) in the pulsed mode, at a power of between 10 and 35 W, and exposure periods of 80, 100 or 200 msec, with intervals of 200-600 msec. The parameters are selected according to the size and area to be treated. The 'no-touch' mode is used with a tip-to-target distance of 1 mm. Assisted by the magnified monitor image, these parameters permit selective treatment of the vessels, sparing the adjoining normal tissue.

For vessels on the septum, the present authors prefer to work at low power settings of 10-15 W, with short periods of exposure (80 and 100 msec) and longer intervals between pulses (200-600 msec), in order to prevent any thermal necrosis of the cartilaginous septum. The corresponding areas on the opposite side should not be treated during the same laser session, in order to prevent irreversible damage to the cartilaginous septum.

6. Capillary haemangiomas

Capillary haemangiomas often show residual convolution, especially if they are located directly on the septum. In order to preserve the septal cartilage during the first session, it is recommended that the penetration depth of the laser be reduced. The effect of the laser on the tissues is tested initially and the lesion is partially treated. Complete excision is deliberately avoided at this stage in order to ensure the integrity of the septal cartilage. A second session is scheduled for six weeks later.

The number of treatments at the *locus Kiesselbachii* (Little's area) depends on whether there is uni- or bilateral involvement of corresponding septal areas. In a poorly stabilised hypertensive patient, the laser usually causes iatrogenic bleeding. Such bleeding should be controlled with packing. Bleeding from a malignant tumour can also be controlled with the palliative application of laser energy, but is usually short-lived.

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MCQ – 28. Laser management of recurrent epistaxis

1. Haemostatic effect of laser is due to
   a. Absorption of laser energy by the red pigment in blood
   b. Coagulation of the blood vessel
   c. Activation of factor 8
   d. Rupture of intact blood vessel and absorption of energy by oozing blood which turns in to char
   e. Collapse of the surrounding structures to seal the ruptured lumen

2. The haemostatic effect of laser beam is achieved when
   a. The laser spot is in direct contact with the bleeding blood vessel
   b. The laser beam is some distance away
   c. The beam is divergent
   d. The laser energy is less than 100^0 C so that the tissues are coagulated rather than vaporised
   e. The laser spot is in sharp focus

3. CO_2 laser
   a. Is an excellent haemostat
   b. Its haemostatic property is due to high absorption of its beam by haemoglobin
   c. Its haemostatic property is limited to blood vessel less that 0.5 mm in diameter and is therefore a poor haemostat
   d. Its use in the control of epistaxis is limited because it cannot be transmitted via optical fibre
   e. Its haemostatic effect (as against its haemostatic property) is very useful in achieving concurrent bleeding due to capillary oozing while using in the management of ENT pathology

4. Nd:YAG laser
   a. Is a good haemostat because its deep coagulative effect due to scatter within the tissue
   b. It is used in the management of epistaxis in defocused mode to obtain diverging beam
   c. A divergent beam vaporises the blood vessel whereas a focused beam coagulates
   d. All of the above
   e. None of the above

5. For controlling epistaxis arising from septal blood vessels
   a. The laser strikes should be in continuous mode to achieve haemostatic effect
   b. The laser strike should be delivered in single shots to achieve haemostatic effect
   c. The blood vessels are approached from periphery to centre where they are more dense
   d. The exposure time should be short and the power density should be high
   e. The exposure time should be short and the power density should be low

6. For epistaxis from a sessile granuloma in the nose
   a. The feeding vessel should be vaporised first
   b. Laser strikes should be carried out on the surface first and then deepened
   c. Laser energy should be high in order to achieve coagulation of deeper tissue
   d. Increasing the energy does not increase the speed of removal of the tumour
   e. A bloodless removal can be achieved by using low powers and short bursts

Chapter 29

Hereditary haemorrhagic telangiectasia

V. Oswal, J. Krespi and A. Kacker

1. Introduction

Hereditary haemorrhagic telangiectasia (HHT) is an autosomal dominant vascular disease, but since the symptoms can be subtle, it may be difficult to elicit a family history of telangiectasia or recurrent bleeding.

Familial epistaxis (most probably of HHT origin) was first described by Sutton in 1864. In 1876, Legg described telangiectasia and hypothesised a primary vascular defect. It was later described in 1896 by Rendu, in 1901 by Osler, and a year later by Weber, when it acquired the eponym Osler-Weber-Rendu (OWR) disease. In 1909, Hanes coined the term hereditary haemorrhagic telangiectasia, and described its characteristic histological findings. Since 90% of cases present with recurrent epistaxis (Rebeiz *et al.*, 1991), HHT is usually recognised as a 'triad' of telangiectasia, recurrent epistaxis, and a family history of the disorder and, in many cases, the patients are first referred to an otolaryngologist. However, significant number first present to gastrointestinal, pulmonary, or dermatology specialists.

Telangiectasia and arteriovenous malformations can be widely distributed throughout the body systems affecting the lungs (25%), brain (14%), gastrointestinal (20%), liver (30%), and genitourinary tracts. The patient may well remain symptom-free for a long time until the lesion manifests clinically, and, devastating strokes and brain abscesses may be the first manifestation of the disease. Clinical screening programmes to detect, for example, pulmonary arteriovenous malformations (AVMs) are available to reduce these complications. Therefore, it is vitally important that the significance of HHT is recognised in these families (Shovlin *et al.*, 2000).

In mucocutaneous lesions, thin-walled endothelial cell lined vessels, resembling dilated postcapillary venules, connect apparently normal capillaries and draining venules. There is a high frequency of direct arteriovenous communications (Shovlin and Letarte, 1999).

HHT results from a mutation in one of at least three genes, endoglin on chromosome 9, ALK-1 on chromosome 12, or a third as yet unidentified locus. These genes encode proteins involved in signalling by TGF-β family members, although the mechanisms by which these mutations result in vascular abnormalities have not been clearly defined. The smallest lesions appear to be dilated postcapillary venules, and larger abnormalities are thought to progress by remodelling.

The affected vessels present as macular telangiectasia, a punctiform spot 1-3 mm in diameter and sharply demarcated from the surrounding tissue. The vessels appear just below the dermis or the mucous membrane, and clinically present as spider-like, punctiform, or nodular lesions, which bleed from trauma or spontaneous breakdown. Additional factors may impair thrombus formation once bleeding begins, particularly type II Von Willebrand's syndrome, but these occasional case reports do not account for the vast majority of clinical cases. It is possible that the abnormal endothelial vessels do not function appropriately in haemostasis. Increased tissue plasminogen activator in the abnormal endothelium may

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impair thrombus formation once bleeding begins.

Mucocutaneous lesions are found, in order of occurrence, on the face, lips, nares, tongue, ears, hands, chest, and feet, often increasing in size and number with age. They are seldom detected before the second or third decade. Spider-like lesions may appear much later.

Population studies in France (Bideau *et al*., 1992) and Denmark (Kjeldsen *et al*., 1999) indicate that the disease is much more common than originally thought, affecting at least one in 10,000 Europeans. The rare homozygous form is usually fatal in young individuals.

Management of patients with hereditary haemorrhagic telangiectasia (HHT) continues to be problematic, with no cure in sight. The objective remains to reduce the frequency and the severity of the episodes of bleeding from the nose, by far the commonest site for these lesions.

2. Nasal manifestations of the disease

The most common symptom is recurrent spontaneous epistaxis, which is usually also the first haemorrhagic event. Typically it begins in childhood or after puberty, before cutaneous lesions have become detectable in size and number. The pattern of epistaxis is variable, ranging from mild to severe.

The classic nasal mucosal lesions are macular telangiectasia measuring 1-3 mm in diameter (Mcdonald *et al*., 1994). These consist of vascular channels lined by a single endothelial cell layer originating from the capillaries and postcapillary venules and, as such, are extremely susceptible to trauma leading to frequent and sometimes severe epistaxis (Byahatti *et al*., 1997). Apart from epistaxis, patients often request the otolaryngologist to treat symptomatic oral mucosal lesions.

3. General manifestations of the disease

Although the condition affects a number of organs, lesions in the lungs and brain are serious and life-threatening. Facial and skin lesions are purely cosmetic, while vaginal and bladder involvement is rare. AVMs are also associated with HHT, forming shunts in the lungs and liver, leading to cyanosis, clubbing, liver cirrhosis, and septic emboli to the brain.

4. Classification of the severity of epistaxis

While the most debilitating symptom for patients is recurrent spontaneous epistaxis, which affects their work and social life, it is not life-threatening. However, life-threatening complications of HHT usually result from pulmonary or cerebral involvement. Rebeiz (1994) established criteria to classify the severity of the disease, as it affects lesions in the nose, into three categories. Mild disease comprises a few episodes of epistaxis per week, with no history of blood transfusions. Moderate disease is said to occur in patients who suffer from one or two daily nosebleeds, and those requiring total blood transfusions of ten units or less for epistaxis during their lifetime. Severe disease constitutes multiple episodes of daily epistaxis, with patients requiring blood transfusions of more than ten units. This classification is probably useful for comparing the effectiveness of various forms of treatment.

4.1. Contact endoscopy of nasal mucosa

Folz *et al.* (2007) examined the nasal mucosa of 17 HHT patients with a 0 degrees contact rhinoscope, Both the areas of the HHT and the normal mucosal were examined in the patient group and the control group. Interestingly, dilated vascular loops and tortuous vessels were found in the study groups as well as in the control group, but the overall density of telangiectatic vessels was, on an average, higher in the HHT group. In the support of the clinical experience, they found that the process of vessel dilatation and tortuous configuration seemed to progress with age. They suggest that the study of the mucosal vascularity may shed some light on the pathophysiology of the nasal disease, but do not offer any definitive correlation at this stage. Nevertheless, we feel that with the introduction of hi-tech instrumentation, further work should be undertaken by research institutions, since, as per the old adage, what the eyes do not see, the mind does not think!

5. Management of epistaxis in hereditary haemorrhagic telangiectasia

Historically, epistaxis has been treated with local pressure, topical vasoconstrictors, chemical and electric cautery, packing, cryotherapy and, in some cases, with arterial embolisation. Some authors advocated septoplasty with the postoperative use of an oestrogen spray, but this did not reduce the frequency or severity of bleeding. Saunders (1960) advocated septodermoplasty, which was successful in about 50% of patients, but had the postoperative complications of septal perforation, nasal stenosis, and persistent epistaxis.

6. Laser management of hereditary haemorrhagic telangiectasia lesions

In the past two decades, focus on the management of HHT has shifted to the use of laser energy. Ben-Bassat *et al.* (1978) used the CO_2 laser, while Parkin and Dixon (1981) and Shapshay and Oliver (1984) chose the Nd:YAG laser. Parkin and Dixon (1981) also reported on their experience with the argon laser. Oswal and Rashad (1997) used the Ho:YAG laser.

7. Treatment protocol based on the type of vasculature

Mahoney and Shapshay (2006) suggested treatment protocol based on the configuration of the tortuosity of the blood vessels in HHT lesions. The records of 40 patients who underwent Nd-YAG laser photocoagulation for HHT were reviewed retrospectively. Outcomes after Nd-YAG laser treatment were correlated with three observed nasal vasculature patterns:

i. isolated punctate telangiectasias or individual small arteriovenous malformation;
ii. diffuse interconnecting vasculature with “feeder” vessels; and
iii. large solitary arteriovenous malformation, which may be associated with scattered telangiectasia.

Types i and ii were the most common vasculature patterns seen in their patient population under study. Patients with patterns i and iii showed greater improvement in epistaxis after Nd-YAG laser photocoagulation. Patients with pattern ii fared better with septodermoplasty. They advocate that an analysis of nasal vasculature patterns using the new classification scheme may rationalise the management of epistaxis in HHT patients with better surgical outcome. This work has not been repeated by other workers, and certainly needs further evaluation.

8. The choice of laser wavelength

More often than not, the choice of wavelength is governed by the availability of a particular laser within the unit. However, there are certain considerations that can govern the choice of laser, if available.

In order to understand the rationale of preferring one wavelength to another, it is necessary to appreciate the effects of laser energy on blood vessels and blood. The vessel wall is made of soft tissue, the components of which contain cellular water. On the other hand, the cellular components of blood contain the red pigment, haemoglobin. As described in Chapter 2, for any tissue effect, all or some of the components must absorb the laser energy. The CO_2 wavelength is strongly absorbed by the water content of the cells constituting the vessel wall. Thus, the vessels and blood are instantly vaporised. Apart from water, the other important constituents are pigments known as chromophores. These chromophores show high absorption to the visible light of the KTP and argon lasers, and to the invisible near-infrared radiation of diode lasers.

Thus, in theory, almost any laser can be used in the management of nasal HHT lesions. However, there are a number of factors that influence the effectiveness of the treatment:

8.1. Size of the lesion

Since the energy of the CO_2 laser is instantly absorbed by cellular water, most of it is spent at the point of contact, with very little lateral or deep conduction. Thus, the spread of energy is adequate to vaporise vessels of less than 0.5 mm in diameter. When a larger vessel is struck with the CO_2 laser beam, only part of it will be vaporised, almost puncturing the wall. The punctured vessel will then bleed, rather than coagulate. Since most vascular lesions in HHT are larger than 0.5 mm in diameter, the CO_2 laser is not the laser of choice for these lesions. The KTP, argon and diode lasers have deeper coagulation zones, and are thus more suitable for these lesions.

8.2. Fibre transmission

The CO_2 laser cannot be transmitted via an optical fibre. Therefore, its free-beam use is limited to the anterior part of the nose. Waveguides can take CO_2 laser energy into the deeper parts of the nose, but they are bulky. There is a significant loss of power during transmission. All the other lasers mentioned

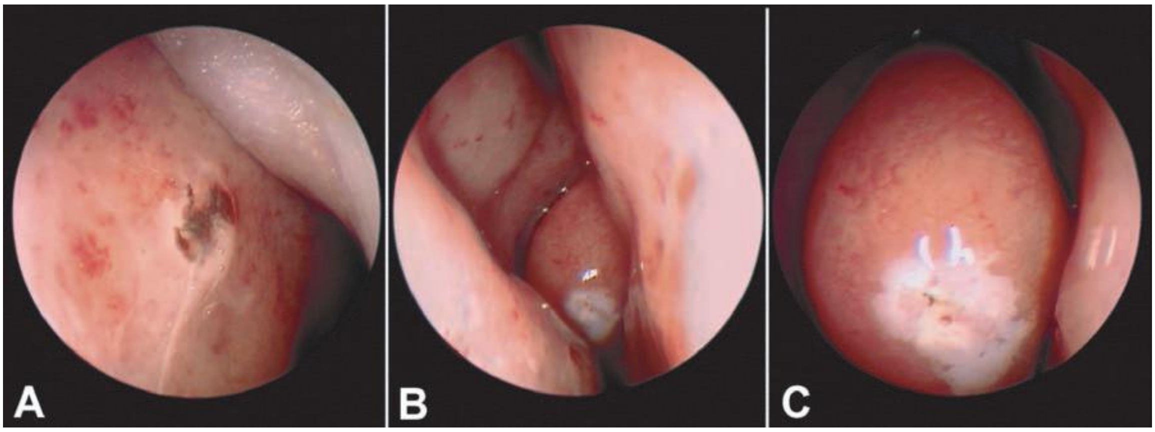

Fig. 1. A. Endoscopic view of the nasal mucosa with hereditary haemorrhagic telangiectasia (M. Osler-Rendu). Vessel convolutions on the septum. B, C. The middle turbinate shows significant blanching after argon laser therapy (3 W, 0.2 sec, 6 Hz). (Courtesy J. Hopf)

above are fibre-transmissible, and their energy can be taken to HHT lesions in any part of the nose.

8.3. High absorption by chromophores

Apart from water, the other important constituents are pigments known as chromophores. These chromophores show high absorption to visible KTP and argon laser light and to near-infrared radiation such as the diode laser (Fig. 1).

The high absorption of KTP and argon wavelengths by haemoglobin helps to seal off the vessels by intraluminal lysis of cellular components such as red blood cells. In addition, the protein in the plasma also suffers thermal coagulation. However, the haemostatic effect of these wavelengths is only possible so far as the vessel is intact. At the power levels used in otolaryngology, it is hard to imagine how the thin endothelial layer of HHT lesions can remain intact and allow intraluminal transmission of the energy for sealing the vessels. It is clear that the use of these wavelengths to seal off HHT vessels is not based on differential chromophore absorption. It is the deep penetration that is responsible for ablation of HHT lesions, and not intraluminal coagulation. On the other hand, the latter is operative in port-wine or any such dermatological vascular lesions rather than in mucosal HHT lesions.

In fact, high chromophore absorption would diminish the effects of tissue ablation in the presence of bleeding, since the blood would absorb most of the energy, with inadequate levels for tissue ablation. Therefore, these wavelengths are only useful when active bleeding is controlled and the energy is reapplied to the vessel wall.

The Nd:YAG laser, in its free beam mode, has much scatter of energy. When used to treat vessels on the septum, there is a risk of septal perforation.

The Ho:YAG laser offers a unique advantage: unlike all other lasers, its thermal effects on HHT lesions continue even in the presence of active bleeding (Oswal and Rashad, 1997). The energy is transmissible both in gaseous (air, CO_2) and liquid (blood, saline) media. The initial part of the energy of the pulse, estimated to be about 20%, divides the liquid, allowing transmission of the remaining energy through the vapour cavity to treat the target tissue. This effect is known as the Moses effect (Holmium: YAG, Health Devices, 1995). Therefore, it is not necessary to have a dry field for vaporisation of the bleeding vessel.

9. Equipment and instrumentation

Apart from the usual instruments for nasal surgery, it is important to have a good supply of ribbon gauze and decongestant, since, in some cases, bleeding may be copious. It is also useful to have bipolar diathermy, as occasionally bleeding may be from a pulsatile artery, which cannot be controlled with laser strikes.

10. Patient counselling

The severity of the disease varies from patient to patient and, therefore, some patients will derive more benefit than others. At the initial consultation, a full assessment of the extent of the lesions and the frequency and severity of the epistaxis is made. The patient is asked about the effects of the epistaxis on his or her lifestyle and work, since these factors will have a bearing on the surgical outcome. The patient is warned that the goal of treatment is to reduce the frequency and severity of epistaxis. The condition is chronic, and frequent treatment will be necessary until a stable condition is achieved, which will enable the patient to cope and possibly to return to work. No cure is possible, since new lesions will continue to appear and will result in further bleeding.

A note is made of the state of the septal mucosa and of any septal perforations already present. When the septum is intact, the patient is warned of the possibility of septal perforation following laser management. Likewise, there is also a possibility of the pre-existing perforation increasing in size if lesions are present on the surrounding mucosa. A blood profile is established and transfusions arranged if necessary. The patient is introduced to a self-help group if this is available.

11. Patient preparation

Irrespective of the wavelength used, there are some salient points in the management of HHT lesions, as follows. It is necessary to ensure that the patient's general condition, and particularly his or her blood profile, is adequate for general anaesthesia. It is also likely that the patient will lose a certain amount of blood during the laser procedure. Decongestants have no effect on bleeding from HHT vessels, since the lesions do not have muscle or elastic walls. However, packing with decongestant is useful since this shrinks all other potential bleeders due to low-grade infection or instrumentation, and makes HHT vessels stand prominent.

12. Anaesthesia

Amongst other factors, such as patient preference and surgeon's experience, the severity and extent of the spread of the lesions governs the choice between topical or general anaesthesia. In a significant number of cases, the lesions are raised 2 or 3 mm above the mucosa. Slight instrumentation trauma or the first laser strike can result in copious bleeding. Moreover, there may be more active bleeders further in, within the nasal fossa. It is best that such lesions are treated under general anaesthesia, which allows prolonged treatment.

When severe lesions are effectively controlled, any subsequent treatment of minor lesions can be carried out under local anaesthesia.

13. Access to lesions

Lesions can be accessed with an endoscope or microscope. If a microscope is used, it is necessary that all lesions at the beginning of the nasal fossa are controlled initially, otherwise they continue to bleed while more posterior lesions are being managed.

14. Laser surgical technique

The laser treatment is aimed at achieving blanching or vaporisation of the offending blood vessel while it is not actively bleeding. This is carried out by approaching it from the periphery, so that the surrounding tissue coagulates and shrivels. As the strikes continue towards the vessel, the coagulation spreads intraluminally, and the vessel is occluded. Further strikes may result in its vaporisation.

14.1. Defocused beam

The energy level is maximum at the focal point of the beam, suitable for ablation. In blanching, the rise in temperature is less than 100°C. The effective coagulation level cannot be achieved simply by lowering the power setting on the control panel.

At a lower power level, the CO_2 beam is still collimated, and retains its ablative power for some distance from its reflection by a mirror in the micromanipulator. For blanching the vessel, the energy is reduced with the lever on the micromanipulator, thus altering the focal distance. The incident CO_2 beam on the target is now defocused and blanching can be accomplished.

When using fibre-transmissible energy, the emerging beam is divergent and not collimated. The incident beam in the near-contact mode is already somewhat defocused. Further defocusing is achieved simply by withdrawing the tip of the fibre further from the lesion.

The use of laser energy in the defocused mode also limits its deep penetration and minimises the potential for septal perforation.

14.2. Bilateral lesions

Patients usually present with epistaxis in both nostrils. It may not be possible to undertake control of bleeders on both sides at one session. In such cases, the side from which the patient has more symptoms is treated, rather than that indicated by clinical examination.

14.3. Bilateral septal lesions

In bilateral cases involving septal lesions, care is taken not to vaporise opposite surfaces during the same session, in order to avoid septal perforation.

15. Management of actively bleeding vessels

If the vessel wall is breached, either by a laser strike or by instrumentation, copious bleeding occurs. Most lasers are then ineffective and their energy is simply wasted for charring blood. It is then necessary to use packing to stop the bleeding before further laser strikes are used to vaporise the vessel. Half-inch ribbon gauze, soaked in decongestant, is inserted into the nasal fossa, and suction is placed on the ribbon gauze. With the nasal fossa firmly packed, pressure is applied to the nostril for a couple of minutes. If the bleeding continues through the pack, it is sucked out. When the bleeding eases off, the pack is gently lifted off the bleeder, which is usually on the septum. When the bleeder is exposed, blood is sucked out, and the laser strikes are used to vaporise the offending vessel. Alternate packing and laser strikes continue until the whole blood vessel is vaporised, which can take a considerable time.

16. Management of hereditary haemorrhagic telangiectasia in cases of septal perforation

When septal perforation occurs, the mucosa around the margin recedes, and the cartilage is exposed. Treatment of bleeding lesions on the mucosa around the perforation inevitably results in further enlargement of the perforation.

17. KTP, Nd:YAG laser and argon lasers in hereditary haemorrhagic telangiectasia

One of the present author (JK) prefers either the KTP or Nd:YAG laser for office procedures. Lesions are first documented using a rigid 0° nasal endoscope. Topical anaesthesia and vasoconstriction is achieved using 4% cocaine solution and 1% lidocaine with 1:100,000 epinephrine topical injections. After satisfactory anaesthesia has been achieved, the lesions are treated using a rigid nasal endoscope and a KTP laser with a flexible fibre set at 2-5 W for 100-500 msec. Lesions are treated in a centripetal fashion, working from the periphery to the centre, until they are blanched. Larger lesions, which are not amenable to KTP laser treatment, are usually treated with the Nd:YAG laser set at 5-20 W for 200-800 msec in the defocused mode, using a suction handpiece. Hopf uses the argon laser for the management of HHT lesions (Fig. 2).

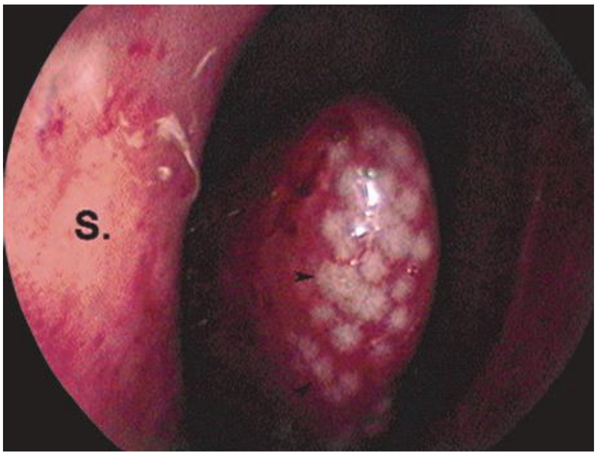

Fig. 2. Appearance immediately after argon laser strikes on the middle turbinate with Osler's disease. (Courtesy J. Hopf)

18. Ho:YAG laser in hereditary haemorrhagic telangiectasia

One of the present authors (VO) uses the Ho:YAG laser (Model Coherent, 2.1 versapulse) (Fig. 3A, B). All procedures are undertaken under general anaesthesia. The Ho:YAG laser is set at 0.4 J per pulse, 12 pulses per second, and the aiming HeNe beam at medium intensity. The energy is delivered to the lesions through a small optical silica fibre, 365 μm in diameter.

The Ho:YAG is a pulsed laser (Holmium:YAG, Heath Devices, 1995). Each strike results in macroscopic disruption of the tissue, causing the vaporised tissues to splatter. When the beam strikes the blood, it also splatters, producing fine droplets. The splattered tissue and blood soil the lens of the fibreoptic telescope (Hopkin rod) and impair the clear view of the target. The so-called endoscope

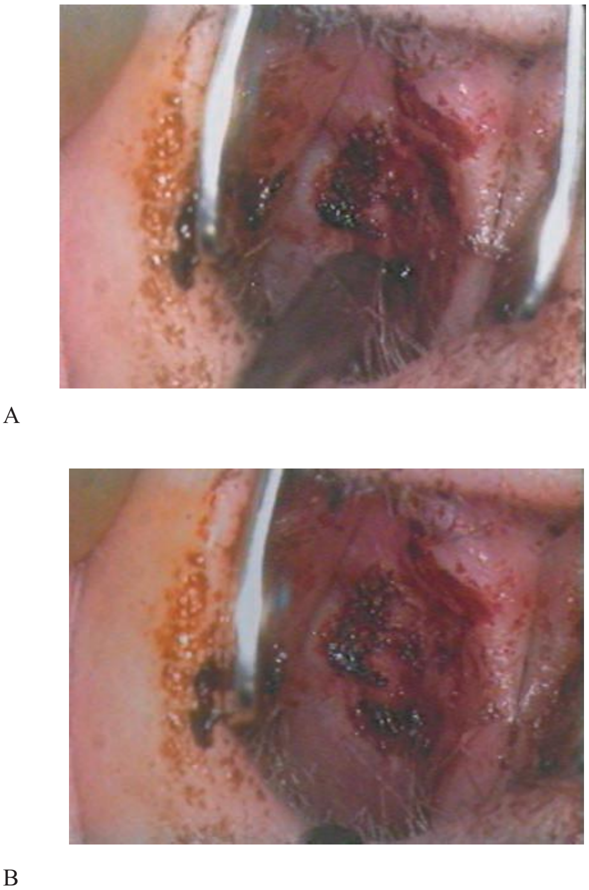

Fig. 3. A, B. Vaporisation of raised lesions from the septal mucosa in haemorrhagic hereditary telangiectasia with Ho: YAG laser.

'scrubbers', designed to flush the lens with saline, are ineffective with the Ho:YAG laser because of the gross soiling. The use of an operating microscope avoids the problems caused by splattering. The 400-mm objective lens of the microscope, being further away from the operating site, remains free of soiling by splattered tissue. Also, a magnified view of the target tissue is obtained. The instrumentation and beam delivery are coaxial. The speculum can be retained in a fixed position by the assistant, freeing the operator's hand for using a second suction handpiece (Oswal and Bingham, 1992). Care must be taken not to cause instrumentation trauma to the lesion.

The fibre is transmitted through a specially designed suction fibre cannula (Oswal suction fibre cannula, Fig. 12 in Chapter 20). This cannula has three channels. The outermost channel, with an overall diameter of 4.1 mm, acts as the main suction cannula and also incorporates two further channels. One of these inner channels takes the optical fibre for laser delivery, while the other extends beyond the main outer channel and acts as a second suction cannula in close proximity to the operating site. Thus, this extended channel continuously removes debris and blood from the operating site, and gives an unobstructed view of the target. A 30° bend in the main outer channel directs the fibre laterally so that the energy can be delivered on the septum or the lateral nasal wall, away from the nasal cavity. This bend also offers a degree of resistance, which grips the fibre firmly and stabilises the tip. Since the emerging beam is divergent, the amount of energy striking the target can be altered within the set parameters by simply varying the distance between the tip of the fibre and the target. The further away the tip is from the target, the larger the spot size, and hence the less the overall energy concentration.

19. Management of hereditary haemorrhagic telangiectasia lesions with the Ho:YAG laser

For small lesions, adequate vaporisation energy is delivered when the tip of the fibre is positioned close to the lesion, one to two mm away, and the lesion struck by one or two direct strikes. As the lesion is vaporised, some of the thermal energy spreads to the surrounding mucosa, causing it to blanch.

For lesions raised above the mucosal surface, the surrounding area is first coagulated, thereby reducing the overall size of the lesion. The energy required for coagulation is less than the vaporising energy. The reduction of energy is achieved by positioning the fibre tip some distance away from the lesion (3-5 mm). The raised area is then struck. Immediate bleeding ensues in the majority of cases, due to a breach in the thin vessel wall. The extended tip of the specially-designed suction fibre cannula helps to remove blood and to facilitate continuous visualisation of the bleeding area. Repeated strikes continue until the lesion is completely vaporised. If the bleeding from the lesions is copious, the nasal cavity is packed with ribbon gauze soaked in decongestant (xylometazoline). The bleeding is easily controlled within a short time and further vaporisation is continued.

At the conclusion of the procedure, debris is cleaned away from the operating site which is then 'rubbed' with gauze. Further strikes are undertaken to control any fresh bleeding until a completely dry field is obtained. Vaporisation of lesions affecting the lips, and tongue is easily accomplished with just a few strikes, and with minimum scarring.

20. Variations in treatment modality

Management of patients with hereditary haemorrhagic telangiectasia (HHT) continues to be problematic, with no cure in sight. The objective remains to reduce the frequency and the severity of the episodes of bleeding from the nose, by far the commonest site for these lesions. Not surprisingly alternative modality find favour with some workers.

20.1. Argon Plasma Coagulation

Argon Plasma Coagulation surgery (APC) is based on a monopolar high-frequency (HF) electrical current transmitted through ionised argon gas from the tip of an applicator to the tissue surface in a contact-free mode. According to Bergler (2003) this new technique has a limited penetration depth and therefore makes APC surgery a safe procedure; damage to neighbouring tissue can be avoided. The author advocates that the APC technique is a useful and relatively inexpensive method to achieve devitalisation of tissues and control hemostasis.

Sadick *et al.* (2003) used Argon Plasma coagulation and topical application of estriol to treat a cohort of 69 patients with a follow up of 20 months. They reported reduction in the frequency and severity of bleeding in 95% cases after 20 months review.

20.2. Radiofrequency

Use of radiofrequency in endoscopic surgery in Otolaryngology is gaining ground, mainly due to its lesser tissue damage and reduced capital outlay. Joshi *et al.* (2011) used radiofrequency in five patients with HHT and obtained control of epistaxis in four out of five patients. They found radiofrequency coblation to be a safe, effective, quick and well tolerated treatment option for epistaxis management in patients with hereditary haemorrhagic telangiectasia.

20.3. Harmonic scalpel

Ishibashi and Takamatsu (2003) used Harmonic scalpel in two cases of HHT and found that the use of the Harmonic Scalpel avoids the carbonisation and crusts of the nasal mucosa that commonly results from electrocautery and laser treatment. Haemostasis could be achieved even during active bleeding.

21. Laser and endonasal Bevacizumab (Avastin)

Rohrmeier *et al.* (2012) injected bevacizumab (Avastin) submucosally in addition to Nd:YAG laser therapy. Doses <7.5 mg were used. A significant improvement in the Epistaxis Severity Score (ESS) resulting from additional bevacizumab therapy was noted ($p < 0.01$). In particular, the frequency of epistaxis ($p = 0.011$), duration of epistaxis ($p < 0.01$), severity of epistaxis ($p < 0.01$) and the need for acute medical treatment ($p = 0.014$) decreased significantly. The haemoglobin levels increased significantly ($p = 0.011$) and the number of blood transfusions declined. There were no side effects caused by the antibody treatment. Their findings indicated that additional injections of a low dose of bevacizumab seem to be superior to Nd:YAG laser therapy alone.

21.1. Is the additional modality Bevacizumab without any side effects?

Between 2006 and 2010, in a large series of 58 patients presenting with recurrent HHT epistaxis, Chen *et al.* (2011) applied Bevacizumab intranasally, either as a submucosal injection or as a topical spray. In many of the injected patients, the potassium titanyl phosphate (KTP) laser was used adjunctively for vessel photocoagulation. 52 patients were surveyed 1.5 to 46 months following their initial Bevacizumab treatment. Within the treatment population, five patients had sustained a septal perforation. Notably, these patients were treated early in the study period at which time the cartilaginous septum was often both injected and lasered.

Subsequently, the treatment protocol was changed and the cartilaginous septum was neither lasered nor injected. After these changes were made no additional septal perforations were identified. No other adverse events were associated with intranasal Bevacizumab treatment.

They conclude that Bevacizumab applied either as a submucosal injection or as a topical nasal spray, with or without application of the KTP laser, is a safe treatment regimen. However, when Bevacizumab injections are performed, the cartilaginous nasal septum should be avoided as patients may develop septal perforations.

Readers should note that septal cartilage is avascular and the blood supply is in the perichondrium. Injecting Bevacizumab under the perichondrium may devitalise the cartilage sufficiently to result in avascular perforation. Deprivation of blood supply may occur further due to selective absorption of KTP energy by haemoglobin in the blood supply, leading to photocoagulation which of course is a desired effect, but not without side effect.

22. Patient risks and benefits

Operative risks are minimum and are mostly related to the disease process with inherent severe intraoperative bleeding. However, this bleeding can easily be controlled with nasal packing.

22.1. Intraoperative bleeding

Intraoperative epistaxis can be very severe, and may result from instrument trauma. The nasal fossa simply fills with blood just as fast as it is sucked out. In such cases, it is not possible to use a laser. The technique described earlier usually solves the problem. In HHT cases, control of severe epistaxis is very quickly achieved by simple pressure with packing, since, unlike normal vessels, HHT vessels are thin-walled.

22.2. Swab count

In cases of copious bleeding, it is necessary to maintain a strict count of the ribbon gauze and to ensure that long lengths are used, with the tail hanging out of the nostril. It is very easy to lose a short length of gauze during the effort to control bleeding quickly.

22.3. Septal perforation

The natural history of HHT leads to life-long episodes of epistaxis. Most patients come to terms with it and learn to control it by self-packing with various materials, such as toilet paper or cotton wool. The packing is left *in situ* for several days, due to the fear of restarting the bleeding when it is removed. Low-grade infection in this area is inevitable in such cases. When the bleeding cannot be controlled at home, the patient presents at the Accident and Emergency department where various treatments, including chemical or electrical cautery and repeated packing, are carried out. Thus, a number of patients presenting for laser treatment may already have a devitalised septal mucosa, or an obvious perforation hidden beneath the crusting or packing. It is important to note any such finding in the records.

It is in the nature of the thermal energy used to seal off or vaporise the vessel, either by electrocautery or lasers, that some devitalisation of the cartilage and perichondrium is inevitable, and, at some stage, a septal perforation may occur. For the various reasons stated above, it is wise to inform the patient about the potential risk of septal perforation, the laser-induced incidence of which is no greater than with any other form of management, provided the precautions described below are taken.

In the case of actively bleeding vessels, repeated strikes to control bleeding do not usually lead to septal perforation since most of the energy is dissipated in the blood. However, if there is no bleeding, then it is necessary to take some precautions to minimise the chances of perforation, as follows:

- a defocused beam minimises deep thermal spread;
- treating both surfaces of the nasal septum at the same session should be avoided;
- repeated strikes should be avoided when the septal mucosa is stretched due to a spur or bucked septum.

In cases where repeated cauterisation has previously been carried out, particularly on one side of the septum, the mucosa may already be severely devitalised. Laser treatment on the opposite side may result in perforation, despite the precautions described above.

One of the present authors (JK) has noted complications in the form of septal perforation related to the use of Nd:YAG laser and recurrent epistaxis. Another of the present authors (VO) has encountered one case of septal perforation following Ho:YAG laser management, in which there was a severely buckled septum with the bleeder situated deep in the groove.

23. Deviated nasal septum and hereditary haemorrhagic telangiectasia lesions

It is difficult to control bleeding posterior to a septal spur or deviated septum, and a number of attempts may be necessary. Sometimes, it is necessary to undertake preliminary septoplasty in such cases.

24. Postoperative morbidity

Postoperative morbidity is extremely low. Patients may benefit from one or more operative session, as per the surgical outcome criteria described below, but they are certainly never worse off after laser management of their lesions.

24.1. Postoperative nasal packing or fibrin spray?

Richmon *et al.* (2007) evaluated the role of fibrin spray in preventing postoperative epistaxis following laser treatment. Nasal packing was used in 30 procedures and fibrin sealant was used in 34 procedures. Six of 30 (20%) procedures using postoperative nasal packing required admission with an average hospital expense of $5914. One of 34 patients (3%) in the fibrin sealant group required hospitalisation ($p = 0.04$). They conclude that aerosolised fibrin sealant prevents postoperative epistaxis after nasal laser treatment in HHT patients. Compared with traditional nasal packing fibrin spray improved patient comfort and recovery with substantial cost savings.

25. Patient benefit: surgical outcome criteria

The surgical outcome should not be assessed too soon. Management is long-term, and the efficacy of each treatment cannot be judged as a success or failure. One obvious benefit must be the decrease in the need for medical management (iron therapy, blood transfusions) between the laser sessions.

A review of the literature shows that it is difficult to compare therapeutic success because each author classifies symptoms and response to treatment differently. Rebeiz *et al.* (1991) used two criteria to judge the effectiveness of management: decrease in the severity of epistaxis; and reduction in episodes of transfusion. An excellent result was a 50% reduction in epistaxis and the number of blood transfusions, for a period of at least eight months. A good response was improvement in symptoms for four to eight months. A fair response was improvement for one to four months, and a poor response was no improvement. Assessment of the success of the surgical outcome based on this classification is rather crude, since it does not take into account what disability the epistaxis may cause to the work and lifestyle of an individual sufferer. The most cogent witness is the patient him- or herself, who can judge the effectiveness of the laser treatment against his or her own past experience.

One of the present authors (VO) admits patients every few weeks and vaporises as many lesions as possible during the operating sessions. The procedure continues until most lesions have been tackled. This results in a steadily increasing benefit from disabling epistaxis. Once a stable condition is reached, the patient is told to make further appointments as and when required.

26. Conclusions

HHT remains a challenging clinical problem. Laser management does not represent a cure or prevent the development of new lesions.

Does HHT affect the quality of life?
It should be obvious to anyone that the HHT, with moderate to severe and frequent epistaxis, has a severe impact on the quality of life of the sufferer. However, in this era of evidence based medicine, Jørgensen *et al.* (2011) set themselves a task of a prospective study to support patients' subjective assessment. Their conclusion was that this group of patients have reduced quality of life compared to the background population. Laser treatment reduced epistaxis in HHT patients with mild to moderate epistaxis for at least 6 months.

Treatment with a laser modality is a useful addition to the management of HHT, a chronic and debilitating condition. Since the condition affects individual patients differently, prolonged, frequent, and tailor-made treatment is necessary. Selection of the wavelength is a matter of availability. Most wavelengths work well, although the CO_2 laser has a disadvantage in that it is not fibre-transmissible. However, it can be transmitted through a hollow, semi-rigid or flexible waveguide. But, these waveguides do not have the same manoeuvrability as that of a small-diameter, silica fibres. KTP, argon, Ho:YAG, and Nd:YAG photocoagulation is a useful, relatively non-invasive therapy for the management of recurrent epistaxis in HHT. Office management depends on a number of factors discussed earlier.

The Ho:YAG laser can manage lesions in the presence of active bleeding and is therefore somewhat superior to KTP or argon lasers. The Nd: YAG laser scatters in the tissues, and is therefore more prone to causing septal perforation.

Even when the utmost care is taken, septal perforation can still occur, due to the prolonged and varied treatment the mucosa has undergone in the past, resulting in scarring, crusting, and low grade infection.

The condition can be treated as an office procedure under topical anaesthesia. However, severe cases need a general anaesthetic. Most patients treated under a general anaesthetic can go home the same day.

In summary, it is necessary to take a pragmatic approach when initiating long-term laser management of this condition, based on following considerations (Oswal and Rashad, 1997):

- The patient should be counselled to the effect that a single laser session is not going to cure his/her epistaxis, or even reduce it in frequency or severity. Lesions are usually multiple and bilateral. It is not possible to pinpoint the lesion responsible for bleeding at any particular time. It is necessary to vaporise as many lesions as possible at any one session. Even then, the offending lesion may not have been included.
- Some extensive lesions need successive vaporisation treatments spread over several sessions. Again, the lesions vaporised at any particular session may not be those responsible for the bleeding.
- Generally, the interval between successive sessions should not be too long since new lesions will appear and grow, with the subsequent difficulty of their management due to copious intraoperative bleeding. They also add to the overall number of lesions.
- Patients suffering from HHT learn to control their epistaxis effectively without hospital attendance. Furthermore, the overall percentage of those requiring hospital attendance is small. Hospital attendance will also be dictated by such factors as ease of access, etc. The success of any laser treatment based on the frequency of hospital attendance may be misleading.
- The patient's version of the effectiveness of laser treatment is a better yardstick than any statistics based on the number of transfusions, etc. Based on this criterium alone, Oswal and Rashad (1997) noted that all their patients found laser management worthwhile and went on to a programme of periodic admissions and vaporisation.

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MCQ – 29. Hereditary haemorrhagic telangiectasia

1. Laser management of HHT is aimed at
    a. Curing the condition so that the patient is free from further episodes of epistaxis
    b. Reducing the severity and frequency of nose bleeds
    c. Prevention of complications such as septal perforation
    d. Controlling the episodes to a point where patient is able to resume his work
    e. Prevent anaemia due to frequent loss of blood

2. In the absence of active bleeding,
    a. It is not possible to locate the bleeder responsible for the episodes of epistaxis and the treatment should be targeted to vaporise and coagulate most lesions
    b. A preoperative decongestant packing shrinks mucosa and thus help visualise the lesions which do not shrink and thus can be targeted
    c. The whole of the nostril and both nostrils should be carefully assessed with an endoscope
    d. All of the above

3. CO_2 laser is not the laser of choice in the management because
    a. It is not transmissible via an optical fibre
    b. It is ineffective in controlling bleeding from vessels no greater than 0.5 mm, and most HHT vessels are larger than 0.5mm in diameter
    c. It has a shallow collateral damage zone and thus vessels rupture rather than coagulated
    d. It is poorly absorbed by red pigment in the blood
    e. All of the above

4. KTP laser is suitable because
    a. It does not require any specific eye ware and thus bleeding point are clearly seen
    b. It is well absorbed by red pigment in the blood
    c. It is fibre transmissible
    d. It is effective even in the presence of active bleeding
    e. It has a good collateral damage zone

5. When treating vasculature of HHT it is advisable to
    a. Start at the centre to quickly tackle the large size vessels which are the major source of bleeding
    b. Start at the periphery so that there is a gradual spread of coagulative zone which is the main mode to seal of the source of bleeding
    c. Start from back to front so that any potential bleeders in the posterior nose are not overlooked
    d. Pack the nostril with ribbon gauze to control active bleeding since the precise point of bleeding cannot be seen in a pool of substantial bleeding
    e. Continue to vaporise the blood until it is completely removed so that a bleeding vessel is clearly seen

6. Laser should not be used when a vessel is actively bleeding
    a. Because the severity of bleeding covers the bleeding area and fills quickly the whole of the nostril
    b. Because all lasers are poor vaporisers of blood covering an actively bleeding vessel
    c. Unless the blood is continuously and effective removed with suction so that the bleeding vessel is clearly seen
    d. Unless active bleeding is controlled with packing and blood vessel is clearly seen
    e. All of the above

7. Laser beam is most effective in coagulating blood vessel when
    a. The beam is defocused
    b. The beam is sharply focused to deliver maximum energy
    c. The beam is at a high power density
    d. The beam is at a low power density
    e. The fibre is held in contact with the vessel to deliver high power for the destruction of the blood vessel

8. As the beam exit the tip of the fibre,
    a. It remains collimated at a considerable distance, thus remaining in focus
    b. It starts diverging and quickly becomes defocused
    c. A collimated beam is more effective in coagulation of the blood vessel
    d. A divergent beam is more effective in coagulation of the blood vessel
    e. None of the above has any effect for coagulating the blood vessel

9. Ho:YAG laser
    a. Is a poor coagulator
    b. Is an effective haemostat as well as vaporiser
    c. Small vessels are coagulated whereas larger vessels are vaporised
    d. Its high pulse energy splatter the tissue debris and blood which often soils the lens of the endoscope which need frequent cleaning
    e. Its high pulse energy may result in perforation of the septum

10. Septal perofration
    a. Is an inevitable complication of the management with laser
    b. The incidence of septal perforation is no greater when laser is used, than other modalities
    c. Repeated management in severe cases leads to devitalisation and avascular necrosis which may play a role in septal perforation
    d. Vaporisation of blood vessels on both sides of the septum at the same operating session does not predispose septal perforation
    e. Has an exposed cartilage and a low grade infection, which results in further enlargement of the perforation

Chapter 30

An overview of laser surgery in the posterior nose/nasopharynx

V. Oswal, F. Martin and S. Triardis

1. Introduction

The posterior part of the nasal cavity (posterior nose, PN) and the nasopharynx (postnasal space, PNS) are anatomically crowded areas. The surgical space is particularly small in very young patients (neonates and infants). The presence of pathology further reduces the space for instrumentation. Clinical diagnosis is mostly based on rigid or flexible endoscopic examination (Levine, 1989). CT scanning has become the mainstay for a detailed assessment of the lesion (Kearns *et al.*, 1988). It is also useful for surgical orientation, so that the management of pathology can be undertaken safely with minimally invasive techniques.

2. Surgical access to the posterior nose and postnasal space

In the majority of cases, access to the PN is obtained by endonasal instrumentation. The endoscope provides a brightly illuminated access, but the image is not magnified. The microscope provides bright illumination as well as magnification, but its use is somewhat cumbersome, and it cannot be used in the presence of anterior nasal obstructions such as a deviated nasal septum or hypertrophied turbinates. The choice between the microscope and the endoscope is largely dictated by personal preference.

The PNS can be accessed endonasally, transorally or transpalatally. The PNS can be accessed endonasally, transorally or transpalatally (Park *et al.*, 2000).

3. Instrumentation

Surgery is undertaken with a variety of cold steel instruments. Their use further impinges on the limited space in the nasal cavity. The 'pull and tug' technique results in bleeding and piecemeal removal of the pathology. Power instruments have solved some of these issues, but they are bulky.

4. Intraoperative haemostasis

The vascular nature of the normal and abnormal structures of the area causes troublesome bleeding, impairing visibility. Bleeding may arise from the anterior part of the nose due to instrumentation trauma. Therefore, initial decongestion is an integral part of surgery of the PN and PNS. Surgery with cold instruments results in intraoperative bleeding, which is controlled by packing with ribbon gauze soaked in decongestant, causing frequent interruption of the surgical progress.

5. Lasers as surgical tools

Laser technology has introduced considerable refinement to instrumentation (Hoffmann and Parkin, 1990). The ablative energy can be taken to the operation site via a very thin optical fibre. Operative progress is not obscured by blood, since intraoperative haemostasis is excellent. In addition, precise, controlled soft-tissue ablation and bone removal

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without avulsion of the tissue reduces morbidity, and results in less postoperative oedema and scarring. The choice of lasers for endonasal surgery, and the basic preparation, has been covered in Chapter 20.

6. Laser safety in the posterior nose and postnasal space

Stringent safety standards prevent stray laser energy from injuring vulnerable areas of the nose and surrounding structures. These include covering the face and eyes with wet gauze such as Gamgee, and inserting wet swabs into the nasopharynx to protect the posterior wall and the eustachian openings. A wet throat pack is inserted between the operative field in the PNS and the oral tracheal tube or laryngeal mask. This also prevents any blood and tissue debris from entering the airway when the tracheal tube is removed at the conclusion of the procedure.

A loss of tactile sensation is apparent when using lasers compared to conventional instruments, particularly when tissue ablation is performed without contact. The collateral and deeper conduction of thermal energy may result in damage to non-target areas. Aggressive use of lasers must be avoided. Instead, the energy is applied in short bursts, and the progress of the procedure frequently appraised by palpation with cold instruments. Any charring should be removed since char burns at a much higher temperature, with resultant deeper thermal spread. The learning curve is much steeper in the crowded and unyielding area of the PN and PNS.

The tissue interactions of various lasers have been discussed in Chapter 2. This section will deal with some specific issues as they are applicable to laser usage in the PN and PNS.

Yuan *et al.* (1993) described a case where neodimium YAG laser was used. Unfortunately, the outcome was fatal, due to gas embolism caused by the nitrogen coolant leaked into the tissue.

7. Various lasers for posterior nose and postnasal space surgery

The CO_2 laser is well established in ENT departments and a number of workers use it in the management of nasal pathology. However, it does have some inherent disadvantages. It is a poor haemostat, an important consideration when dealing with highly vascular nasal mucosa. Lack of transmission down the optical fibre means that posterior access is extremely difficult in the presence of turbinate hypertrophy, septal deviations, a high arched hard palate, and craniofacial anomalies. The CO_2 laser is not a good bone ablator. If there is no choice, then its use can be facilitated by initial good decongestion of the nasal fossae and the use of waveguides. However, waveguides are bulky and there is some energy loss during transmission. Newer waveguides have much improved in design. These are described in detail in Chapter 59.

Most fibre-transmissible lasers (argon, KTP/ 532, Ho:YAG, Nd:YAG, diode) are suitable, and they all have adequate haemostatic properties (Tzifa and Skinner, 2001; Pototschnig *et al.*, 2001). However, Nd:YAG energy has a high scatter within the tissue unless it is used in the contact mode. The diode is only effective in the contact mode when used with energy suitable for nasal work. A particular disadvantage of the contact laser is that the ablation effect is obscured by the contact tip, and thus lacks precise visual control to a certain extent.

8. Surgical technique

Due to the anatomical crowding in the space, it is best to use intermittent exposures to ablate the tissue. Frequent transoral and postnasal assessment helps orient the direction of ablation. Initial bimanual palpation with an instrument passed transnasally and palpated in the postnasal space is useful for orientation. Retrograde transillumination from the postnasal space, particularly in cases of stenosis or atresia, is another useful technique.

The argon laser is suitable for excision or photocoagulation of pigmented or vascular intranasal lesions (granuloma, haemangioma). Care must be taken to avoid photocoagulation directly on the opposing surfaces of the nasal septum (risk of perforation).

The KTP/532 laser is extensively used in all forms of nasal surgery since it combines a very small spot size with fibreoptic delivery system. It is used variously to cut, coagulate and vaporise.

The Nd:YAG laser is The Ho:YAG laser has a good haemostatic property, defined soft-tissue ablation, and precise bone-removing properties (Panwar and Martin, 1996). Its narrow zone of heat transmission limits scar formation, and while, in animal studies, healing is somewhat delayed compared with conventional surgery, no deeper vascular damage was noted, making delayed tissue necrosis less likely.

9. Clinical indications for laser usage in the posterior nose

The pathology of the area includes the hypertrophic posterior end of the inferior turbinate, choanal atresia or stenosis, nasopharyngeal stenosis, and space occupying lesions (polyps, adenoid hypertrophy, juvenile angiofibroma and nasopharyngeal cancer). The use of lasers in such situations must demonstrate a clear advantage over more conventional methods. Laser ablation of large volumes of tissue is painfully slow. It may be that the bulk of the tissue could be removed with cold or powered instruments and that the laser be used in the final stages of clearance when its advantage in effecting haemostasis and its ability to deliver energy in confined, inaccessible places are most obvious. The eustachian tube pathology usually remains undiagnosed and untreated because of inaccessibility. Chapter 31 covers usage of lasers in some common nasal and nasopharyngeal pathology. Chapter 37 covers laser management of Eustachian tube pathology.

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MCQ – 30. An overview of laser surgery in the posterior nose/nasopharynx

1. One most useful investigation for preoperative assessment of the nasal and postnasal pathology is CT scan because
   a. Nasal passages are dark crowded cavities
   b. Outpatient endoscopy is not adequate on account of reduction of space by the presence of pathology
   c. Neonates and infant nasal passages are inherently narrow
   d. Various orientations provide useful information to plan surgical strategy
   e. All of the above

2. Endonasal postnasal laser surgery
   a. Needs specialised training, even where expertise for FESS has been accomplished
   b. Needs fibre transmissible laser wavelength in order to achieve optimum results
   c. Is associated with much postoperative oedema and scarring
   d. Has an increased incidence of postoperative bleeding episodes
   e. Is cost effective

3. Disadvantages of endonasal laser surgery include
   a. High capital outlay
   b. General anaesthesia
   c. Single use specification for fibres for some lasers such as KTP, with revenue implications
   d. Inability to use microscope for magnification
   e. Intraoperative bleeding obscuring adequate view of the target

4. Following lasers have poor haemostatic property for endonasal laser surgery
   a. Ho:YAG
   b. KTP-532
   c. Argon
   d. Nd:YAG
   e. CO_2

5. Prior to a surgical procedure, pre-operative assessment of postnasal pathology is facilitated by:
   a. Removal of obstructing anterior pathology such as deviated nasal septum
   b. Passage of endoscope via patent side
   c. Manual palpation via oral cavity
   d. Transillumination via nasopharynx
   e. Decongesting nasal mucosa

6. Laser surgery for bulky pathology
   a. Is time consuming
   b. Obscures anatomical landmark due to charring
   c. Should be removed with conventional instruments followed by laser for final stages
   d. Results in excessive bleeding
   e. Is associated with increased incidence of complications

Chapter 31

Laser management of pathology in the posterior nose/nasopharynx

V. Oswal, S. Karpischenko, J. Krespi, F. Martin and S. Triardis

Part A: Laser interstitial thermo therapy (LITT) in the management of nasal and nasopharyngeal papillomatosis

S. Karpischenko

1. Introduction

Although the condition of papillomatosis is termed recurrent *respiratory* papillomatosis, the lesions mainly appear in the larynx, the site of predilection. The respiratory nasal and nasopharyngeal mucosa is rarely affected with papillomatosis. The possible aetiology is iatrogenic implantation when the nasal anaesthetic tube is withdrawn following management of laryngeal papillomatosis.

Cold instrument management is difficult for nasal and nasopharyngeal papilloma due to limited access and bleeding. The lesions may be massive, and involvement of nasopharyngeal surface of the soft palate is particularly inaccessible to cold instrumentation, with a possibility of further iatrogenic implantation at different sites.

Laser technology offers an elegant method to tackle these lesions. A fibre transmissible laser such as the diode laser can be used endoscopically to vaporise isolated lesions. However, massive lesions in these locations require a considerable time consuming vaporisation and the removal may be incomplete.

In such cases the author has used the laser energy interstitially to affect tissue ablation. The technique is variously known as laser interstitial thermal therapy (LITT), interstitial laser thermotherapy (ILT) and interstitial laser photocoagulation (ILP). Interstitial tissue ablation with laser has been used in other anatomical locations and also for various pathological conditions, described under paragraph 6.

2. Basic science

LITT consists of delivery of laser energy with optical fibre within the solid tissue such as prostate or metastatic focal deposits in brain, liver and bone (Stafford *et al*., 2010). Stereotaxic placement of a saline-cooled interstitial fibre-optic laser applicator is undertaken under local anaesthesia. Real-time temperature sensitive information is extracted by computer under magnetic resonance (MR) guidance. A device that controls the heat at the tip of the fibre, the Fibertom®, is available commercially and is described in Chapter 4.

This technique offers a high-level feedback control over laser delivery and enables a minimally invasive option for destruction and treatment of resistant focal, primary or metastatic tumours, in office setting.

3. Laser action

At around 56-70^0 C, the laser heats up the tissue and coagulates the protein of the cells. The denatured protein is absorbed over time and the bulk of the solid tissue is reduced. The laser energy also coagulates the blood vessels, thereby cutting off the blood supply to the tissue not directly affected

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by the action of the laser. This tissue, deprived of blood supply, undergoes avascular necrosis which further reduces the bulk.

If the bulk is pedicled, as in the case of most nasal polypi, laser energy delivered to the pedicle alone will cause avascular necrosis and, over time, the polyp will detach from the mucosa and expelled, perhaps with a sneeze. By continuing the exposure, the whole polyp can be removed bloodlessly at the time of surgery.

LITT may also induce changes in immunocompetent cells, as reported by Haraldsdóttir *et al.* (2011) in patients with breast cancer described later under paragraph 6. The stimulation of the immune system may be an added feature of LITT.

4. Commonly used lasers for LITT

4.1. Semiconductor diode laser

The diode laser light is produced by using light-emitting diodes (LEDs) between reflecting mirrors in a resonator tube. The diode lasers are smaller, more efficient, and potentially cheaper than most other lasers now in use. They require virtually no maintenance. Their wavelength can be tuned by adding various elements (*e.g.*, aluminum, indium). An 810-nm laser is produced using Aluminium Gallium Arsenide (AlGaAs), and a 905 nm, 980 nm, 1060 nm, or 1300 nm. beam is produced from the active compound Indium Gallium Arsenide (InGaAs).

4.2. Nd:YAG laser

Nd:YAG laser is has also been used because of its deep penetration and fibre delivery.

5. Other modalities for interstitial tissue ablation

The interstitial ablation of the tissue can also be carried out with radiofrequency, microwaves, cryotherapy or ultrasound energy.

6. Literature review

As long ago as 1992, Castro *et al.* undertook evaluation of LITT in *ex-vivo* and *in-vivo* models. There was a linear relationship between levels of laser energy, thermal profiles, MR signal intensity changes, and histopathological tissue damage. Based on the study, they used LITT in a patient with an unresectable large right jugulo-digastric metastatic squamous carcinoma. The patient complained of significant right-sided neck pain and headaches secondary to a rapidly growing metastatic lymphadenopathy which recurred after previous surgery, radiation, and chemotherapy. Two treatment sessions were used at an interval of two weeks. Each treatment was performed in the MRI suite under heavy sedation. Using a 600-microns bare fibre Nd:YAG laser, energy was delivered interstitially under MR guidance. The metastatic node was treated at three sites. T1- and T2-weighted images were performed prior to, immediately after, 24 and 48 hours, and four, five, seven, nine, 16, and 25 days post-treatment. Successful relief of pain and growth arrest of the node was observed after the second treatment and at the three-month follow-up. These results showed that LITT guided by MRI may be feasible, and become clinically practical when appropriate methods of dosimetry and instrumentation are developed.

Bockmühl *et al.* (1996) used LITT in five cases of head-and-neck squamous-cell carcinoma which had failed conventional management. Nd:YAG laser was used to treat the tumours with LITT technique. One patient with laryngeal carcinoma, who refused surgical management was treated with LITT and radiation. The tumour necrosis ranged from 4-28 cm^3. In all cases, MR thermo-sequences showed loss of signal up to 15 mm around the tip of the applicator. The coagulation necrosis was represented as hypovascular areas. No side effects were observed and all five patients reported improvement of clinical symptoms.

This work was followed by a report by Eyrich *et al.* (2000) who treated four patients with lymphangioma of the tongue and neck with LITT. In three patients, MR clearly showed a reduced tumour volume. All four patients reported subjective improvement and in three patients there was an improvement in speech and swallowing functions. MR thermometry allowed accurate demarcation of changes by heat and assessment of tumour volume (3.0 cm ± 0.3 cm). The histology of the patients six months after LITT showed laser-induced fibrosis of previous lymphatic tissue.

Atsumi *et al.* (2001) assessed the effects of LITT in the management of intracranial tumours. Bare-tip fibre resulted in spherical temperature profile whereas diffuse-projection fibre system produced a cylindrical temperature distribution. Exposure to high and continuous laser energy resulted in carbonisation, particularly when bare tip fibre was used. They concluded that the use of a diffuse-projection fibre system used for delivery of energy intermittently was an effective tool to regulate temperature during LITT using MR temperature measurement.

Haraldsdóttir *et al*. (2008) used LITT to treat small breast cancers for radical treatment. They concluded that the method may become useful in the treatment of breast cancer, but needed further refinement, particularly if advised as *radical* treatment, even for small well-defined breast cancers.

Dowlatshahi *et al*. (2010) reported LITT in two patients with breast fibroadenomas with a follow up of six and eight years.

Amabile *et al*. (2011) used LITT for the ablation of non-functioning and hyper-functioning benign thyroid nodules. They concluded that the LITT represented a valid alternative to surgery for large benign thyroid nodules, both in terms of nodule size reduction and cure of hyperthyroidism.

Carpentier *et al*. (2011) researched the feasibility of using gold nanoshells (AuNS) intravenously for tissue ablation. The gold nanoshells (AuNS) can be tuned to absorb light in the range used for laser ablation. When injected intravenously, and the tumour exposed to the laser light, the nanoshells convert the tumour vasculature into a potent heating source for nanoparticle-mediated ablation at power levels which did not generate significant damage in normal tissue.

Wiggermann *et al*. (2012) undertook a pilot clinical trial exploring the safety and feasibility of thermal ablation of unresectable intracranial tumours and reported that the real-time magnetic resonance (MR) guidance of laser-induced thermal therapy (LITT) offers a high level of control.

Haraldsdóttir *et al*. (2011) studied changes in immunocompetent cells following local tumour destruction with LITT in seventeen women suffering from breast cancer. LITT was used initially with a steady-state temperature of 48° C for 30 minutes. Surgical excision was performed 12 days (6-23) after LITT. Six patients who were not treated with pre-op LITT served as control. Their investigation showed that LITT treatment induced changes in immunocompetent cells in patients with breast cancer and that the stimulation of the immune system is an added feature of LITT in treatment of patients with breast cancer.

7. Tissue penetration of contact diode laser

The author investigated the extent of penetration of contact diode laser. Solitary lesions appearing on the edge of veli palatine in patients undergoing laser uvulopalatoplasty for snoring were excised with contact diode laser and the depth of the coagulation zone was studied. At the power setting 1.5 to 2.0 W, the basal membrane was entirely preserved. The basal membrane vasculature was also unaffected.

Excised papilloma was exposed to contact diode and the specimen was examined histologically. It was noted that the spread of the laser energy was uniform and spherical from the tip of the fibre.

8. LITT management of nasal and postnasal papilloma

Based on these results, the author treated an extensive nasal lesion with LITT, as described here. A 23-year-old male, with a history of several laryngeal interventions for recurrent respiratory papillomatosis presented to the ENT department of I. P. Pavlov Medical University, St. Petersburg, Russia. He complained of nasal obstruction, rhinolalia and headaches. Nasal endoscopy showed a complete blockage of the posterior nose with papilloma. There were lesions on the soft palate and anterior and posterior pillars. Larynx was free from any lesions.

A CT scan (Fig. 1) showed a massive lesion extending well in to the nasopharynx.

Microdebrider was used under a general anaesthetic to remove the mass. However, severe bleeding ensued and it was impossible to obtain adequate view of the lesion. The procedure was abandoned.

Under local anaesthesia, LITT was performed with contact diode laser set at 2 W (Fig. 2 A-E).

A 600-um fibre was used to puncture the mass and the fibre tip was advanced. Alternative laser delivery and advancement of the fibre was carried out until there was a visible blanching of the surface of the lesion. The laser exposure was stopped and the fibre withdrawn. The blanched specimen was removed bloodlessly with suction. The procedure was repeated two days later, under local anaesthesia. There was a clear demarcation zone between the excised margin and the remaining mass. A total of three procedures during one week of LITT management achieved almost bloodless clearance of extensive papilloma which had blocked the nostril and the nasopharynx completely. There was very little postoperative discomfort or oedema and no

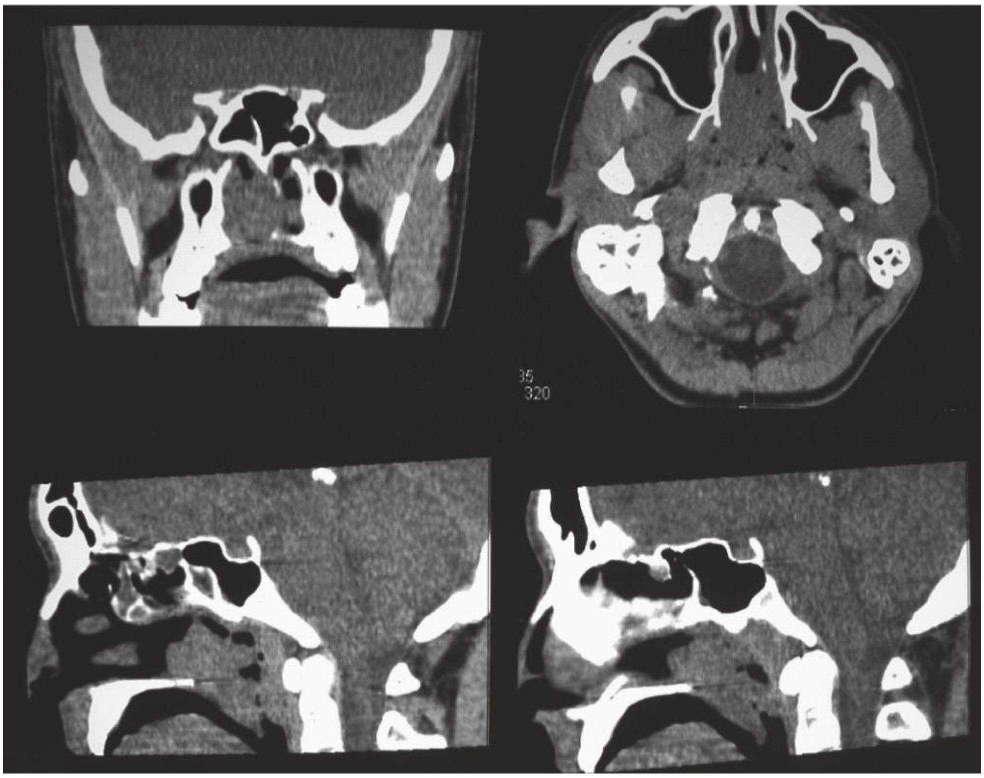

Fig. 1. CT-scan showing massive obstruction of the right nostril.

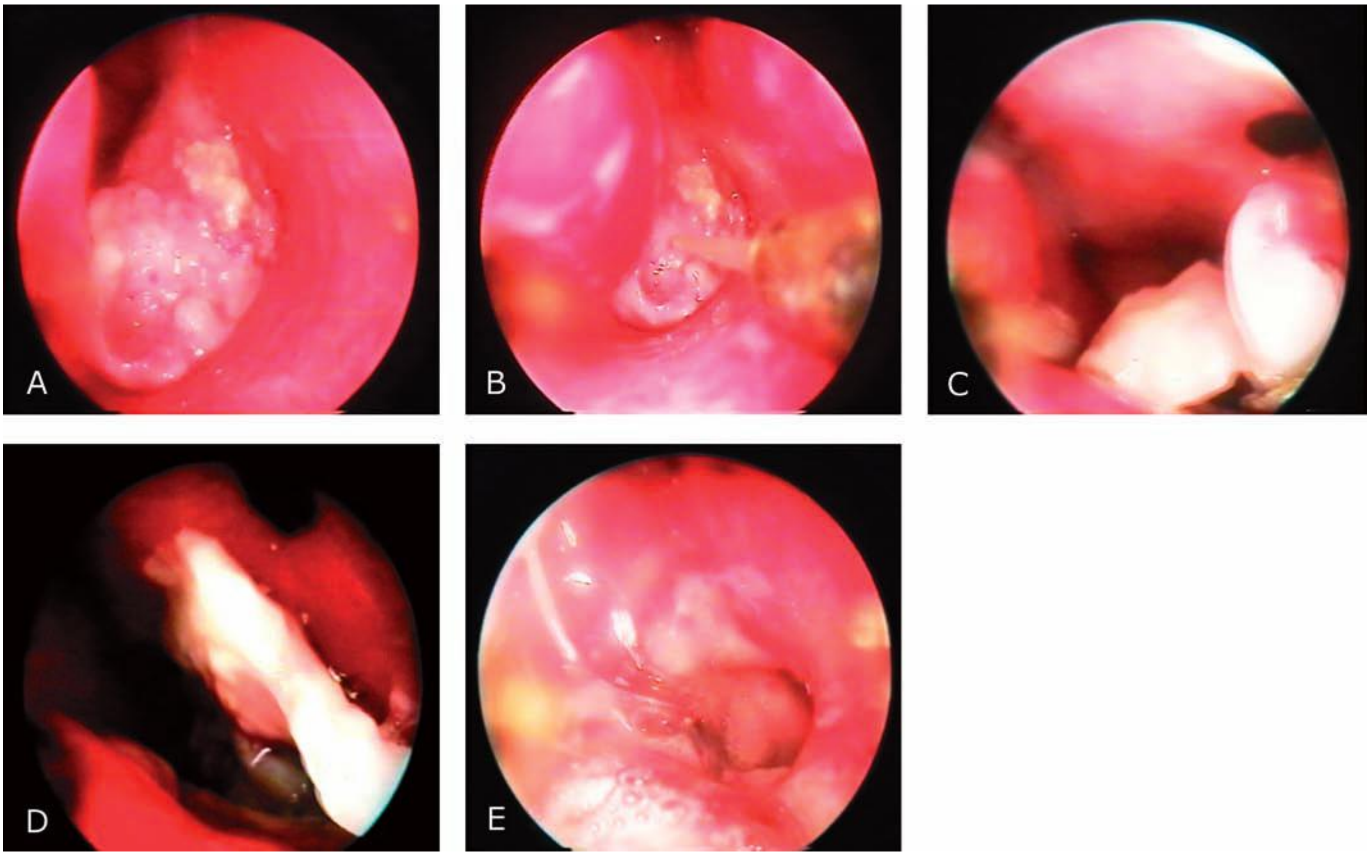

Fig. 2. A: Massive papilloma in the left nostril; B: Interstitial placement of optical fibre; C: Coagulated papilloma; D: Removal with suction; E: Clearance of the nasal cavity after three sequential procedures, showing posterior choana.

packing was necessary. Other lesions were excised conventionally.

9. Discussion

Nasal and postnasal (PN) recurrent respiratory papillomatosis is a rare condition, either *de novo* or in established cases of laryngeal papillomatosis. Since the onset is insidious, most patients present when the blockage is well advanced on one side. The extent and the size of the lesion is difficult to manage, since the access is limited and bleeding obscures adequate view. Endoscopic removal with cold instrumentation is inadvisable since it may precipitate iatrogenic implantation. Peters *et al*. (2011) reported a case series of three patients managed successfully with coblation without any complications. There was recurrence in one patient; this was also successfully managed with coblation.

The author used contact diode laser for laser interstitial thermo therapy (LITT). The heat at the tip of the fibre spreads evenly in a homogenous papilloma. The protein denatures at 56-70° C. Intermittent strikes avoid carbonisation. Visual control of the extent of laser damage is adequately provided by blanching of the lesions. The procedure is stopped when blanching of the visual part of the lesion is complete. The treated mass is removed with gentle suction and does not result in any bleeding. Further removal is carried out sequentially until the nasal passage is clear. The procedure is office based, and thus convenient and cost effective. Any sessile lesions are either excised or vaporised. The procedure is well tolerated by the patient and a complete clearance can be achieved successfully with sequential removals. The endonasal LITT is free from any complications since it is entirely under visual control and does not require real time MR for demarcation of necrotic zone. In the postnasal space, lateral wall is treated with caution to avoid any damage to the Eustachian tube orifice.

Part B: Laser management of choanal atresia

V. Oswal, J. Krespi, F. Martin and S. Triardis

10. Introduction

Posterior choanal atresia (Figs. 3 and 4) is an uncommon congenital anomaly, first identified in the 18th century and surgically treated in 1851 by Johann Roderer. If present bilaterally, it has potential life-threatening consequences since neonates are obligate nasal breathers. Such cases require immediate airway management by means of placement of an anaesthesic oral airway, intubation and/or tracheotomy. Laser management of such cases is critical, due to the high level of time-consuming equipment preparation required.

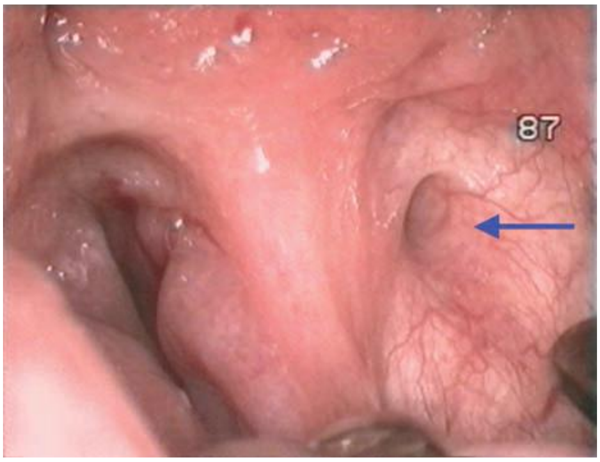

Fig. 3. Unilateral choanal atresia. (Courtesy, M Remacle)

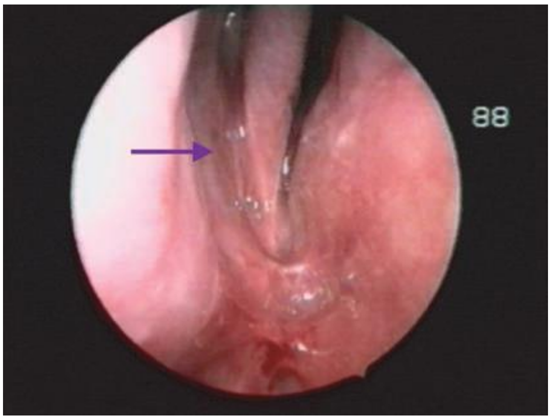

Fig. 4. Partial choanal atresia.

Unilateral atresia does not usually cause respiratory distress and does not warrant immediate intervention. Definitive therapy is usually performed before the patient starts school, in order to stop nasal discharge.

Choanal atresia occurs in one in 5000-8000 live births, with a 2:1 female-to-male ratio. Unilateral cases outnumber bilateral cases by two to one. Other congenital anomalies are present in 50% of choanal atresia patients. Associated abnormalities are more frequently seen in bilateral cases (up to 75%). The multiple congenital anomaly is described by the acronym CHARGE (coloboma, congenital heart disease, atresia choanae, retarded growth and development, genital anomalies in males, ear anomalies and deafness). Other abnormalities are polydactyl, nasal-auricular and palatal deformities, Crouzon's syndrome, craniosynostosis, microencephaly, meningocoele, facial asymmetry, cleft palate, and hypertelorism. The wide variety of associated abnormalities highlights the importance of undertaking a comprehensive assessment of any child with choanal atresia (Kaplan, 1989).

11. Embryogenesis of choanal atresia

A detailed description is beyond the scope of this work. Briefly, atresia occurs due to one or more of the following factors:

- persistence of the buccopharyngeal membrane from the foregut
- persistence of the nasobuccal membrane of Hochstetter
- abnormal mesodermal adhesions forming in the nasal choanae, and
- misdirection of mesodermal flow due to local factors (Hengerer and Strome, 1982, Josephson *et al*., 1998; Keller and Kacker, 2000).

11.1. Types of anatomical deformity

The four types of the anatomical deformity include a narrow nasal cavity, lateral bony impingement by the pterygoid bone, medial obstruction by a thickened abnormal posterior vomer, with or without a central membranous obstruction.

12. Symptoms

Patients with bilateral choanal atresia present with the immediate onset of respiratory distress at birth with cyclical cyanosis (cyanosis relieved by crying, returning when crying stops), since neonates are obligate nasal breathers. In contrast, patients with unilateral choanal atresia often present with unilateral nasal discharge and ipsilateral nasal obstruction, later in life.

13. Diagnosis

Diagnosis is usually made by the inability to pass a small (No. 5 or 6 French) suction catheter transnasally into the nasopharynx. The catheter should either be seen or palpated in the oral cavity in order to prevent misdiagnosis due to the catheter coiling in the nose. The diagnosis can be confirmed by performing a flexible fiberoptic nasopharyngoscopy. CT scanning is advised in all cases, since it defines the nature and thickness of the atretic plate and helps in the preoperative planning. The atretic plate can be entirely membranous (10%) or bony (90%), however, a combination of bony and membranous components seems to be common (Hengerer and Strome, 1982). In a more recent publication, 29% was found to be completely bony, 71% mixed bonymembranous, and 0% membranous (Brown *et al*., 1996). The thickness of the bony atretic plate can measure from 1-12 mm (Hengerer and Strome, 1982). Axial scanning (Fig. 5) is particularly useful since it shows the configuration of the entire nasal cavity (Kearns *et al*., 1988). Other radiological pro-

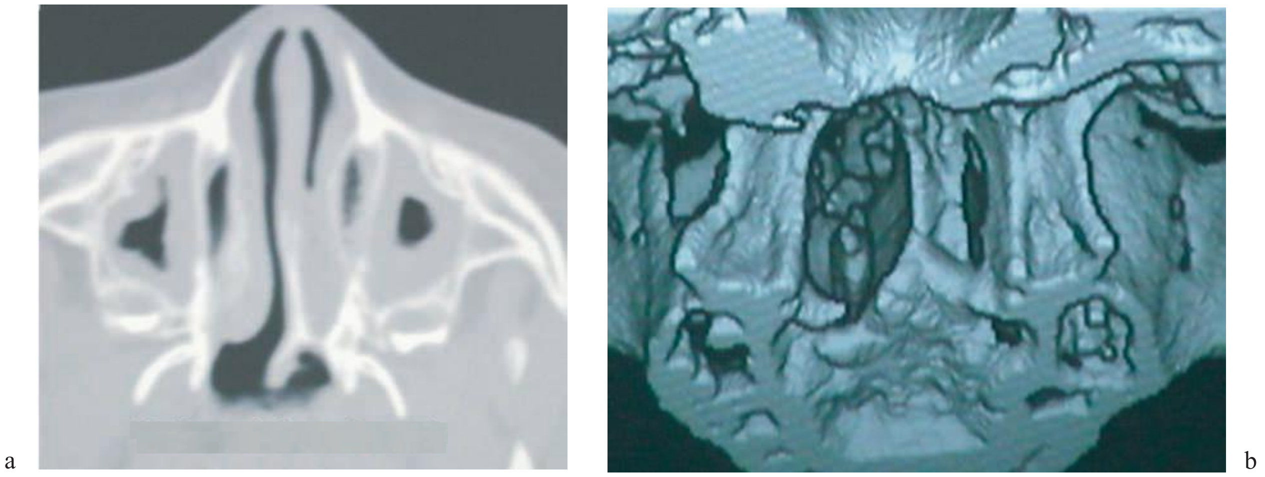

Fig. 5. a. Unilateral choanal atresia. b. Imaging of chaoanal atresia.

cedures include placing radioopaque contrast into the nasal cavity. It is necessary to remove the discharge with suction since its presence prevents the dye from reaching the true location of the atresia.

14. Conventional management

Since the earliest documented technique (a blind transnasal puncture through the atretic plate) by Emmert in 1854, a variety of techniques has been used for the surgical correction of choanal atresia, including transnasal, transpalatal, transseptal, and transantral approaches. The transnasal route, although simpler, quicker, and easier to perform on neonates and young infants, became unpopular and fell into disrepute because of the high incidence of restenosis requiring revision. This was due to the difficulty of visualising the surgical site (Josephson *et al*., 1998). The transpalatal route became the method of choice for many surgeons since it offers excellent exposure and is associated with high success rates, a decreased incidence of restenosis, and reduced duration of stenting. The transpalatal route requires greater tissue handling, which results in increased operative time and blood loss, and may be complicated with palatal fistula, palatal muscle dysfunction, and maxillofacial growth disturbance with subsequent crossbite deformity (Park *et al*., 2000).

With the advent of endoscopes and improvement in endoscopic surgical techniques, the endoscope-assisted transnasal approach has become the technique of choice. The introduction of lasers and powered instrumentation has added surgical precision and has opened up a new dimension in the management of choanal atresia via the transnasal route.

15. Choice of laser

Although almost any of the lasers commonly available in the ENT department can be used, some have better energy and delivery parameters for choanal atresia. A fibre-transmissible laser with good ablative properties for soft tissue as well as for bone, and adequate intraoperative haemostasis, is the most suitable. The Ho:YAG has superior bone ablation properties, it allows precise vaporisation of the membranous or bony atretic plate under direct visual control, in a bloodless field with minimal injury to the adjacent tissues (Panwar and Martin, 1996). The KTP laser ablates both the membranous and bony components of the atresia with concurrent haemostasis. It has little risk of perioperative or wound healing complications. Regeneration of the mucosa with epithelisation takes place within ten to 14 days after laser surgery (Pototschnig *et al*., 2001). The diode wavelength is equally acceptable.

The CO_2 laser is the least suitable since its delivery via a waveguide is cumbersome, and it is a poor haemostat. If used to vaporise the bony atretic plate in the continuous mode, at low powers there is excessive charring, and at high powers there is a danger of dissipation of heat to the surrounding tissue, leading to necrosis, sequestration, and scarring. The optimum work is done by using a high power setting, in the repeat mode with short bursts, and frequent removal of charred debris. Delivery through an operating microscope is problematic in the presence of proximal obstructing conditions (Fong *et al*., 1999). The Nd:YAG laser causes deep thermal tissue injury and requires coaxial gas cooling (Yuan *et al*., 1993).

16. Surgical technique

Surgery for unilateral choanal atresia is performed as an elective procedure, and therefore the use of laser technology is appropriate. All procedures are performed in the operating room under general anaesthesia.

The transnasal technique is made safer by using a Gruber aural speculum (its long, narrow neck traverses the whole length of the nostril giving an uninterrupted view of the choana). Operating from a tonsillectomy position allows the surgeon's view to be focused on the choana itself (Singh, 1991).

Some common steps from the many techniques described in the literature include initial vasoconstriction of the nasal mucosa, protection of the nasopharynx (moistened gauze, cottonoids), vaporisation of the atretic plate with the laser, starting medially along the floor and the posterior nasal septum and moving laterally. Further enlargement of the neochoanae is carried out by shortening the posterior-thickened vomer and creating a common cavity posteriorly (Brown *et al*., 1996; Fong *et al*., 1999). The use and role of nasal stenting for preventing restenosis is discussed later.

Postoperative care includes nasal irrigation and steam inhalation. In Tzifa and Skinner's (2001) series, a 100% success rate was reported at 12 months, without any complications.

17. Patient risk and benefit

17.1. Benefits

These include a minimally invasive procedure without having to resort to a transpalatal approach in most cases. The inpatient stay is short, and the surgical outcome satisfactory (Fig. 6a,b). Intraoperative risks are low, provided adequate precautions are taken to ablate the appropriate tissue by locating it with the help of CT scanning and postnasal palpation. If possible, an attempt should be made to perforate the atretic plate with a trocar. Its position in the postnasal space should be assessed, and the opening enlarged around it in a medial direction. Transillumination of the posterior nose by positioning a flexible light pipe in the postnatal space is useful for obtaining orientation. The rate of restenosis with laser surgery is comparable to other techniques, and may even be less. This is discussed in the following section. Postoperative morbidity is extremely low.

17.2. Restenosis of choana

It is suggested that, if restenosis is to occur, this will happen within the first 12 months after the operation (Fig. 7). While initial results were excellent, on long-term follow-up, Healy *et al*. (1978) and Duyne and Coleman (1995) reported a rate of restenosis of 25-30%, regardless of the type of laser used. They further reported that cases of restenosis from scarring are easily revised using a laser, with patency rates of over 90% being achieved after the second laser excision.

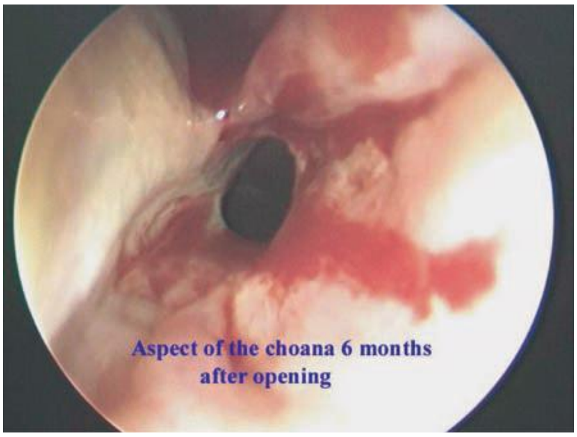

Fig. 7. Opening, six months after the operation. (Courtesy, M. Remacle)

Crockett and Strasnick (1989) and Hengerer and Strome (1982) recommend that patients with a significant bony component to the atresia or a lateral bony narrowing of the nasal cavity are best treated by surgery via the transpalatal approach, through which an adequate amount of lateral bony wall and posterior septum can be removed safely.

17.3. Oral fistula

With the transpalatal approach, incomplete healing of the incision may result in oral fistula. Laser surgery also has a potential for this complication, due to conduction of thermal energy beyond the target tissue. This can be avoided by using the laser energy in the repeat mode in order to allow cooling between strikes. Charring of the bone should be removed frequently since char heats up at a much higher temperature, thus resulting in collateral heat conduction. The laser beam should not be held in one position for a long exposure, but be moved in

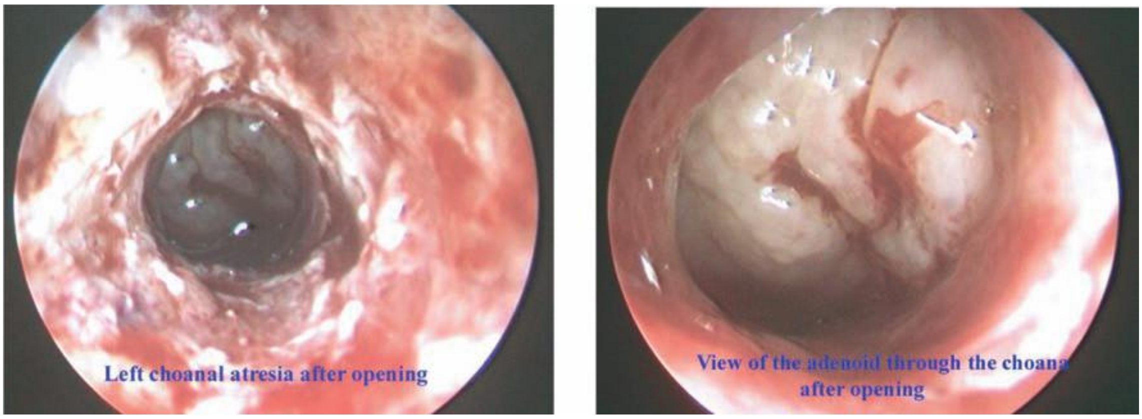
Left choanal atresia after opening
View of the adenoid through the choana
after opening

Fig. 6. Left choana opened after removal of atretic plate. Adenoid tissue seen through the opening. (Courtesy, M. Remacle)

a paintbrush pattern to prevent deep penetration of the heat.

17.4. Use of stents

Stents are placed postoperatively to allow nasal breathing and to prevent restenosis during re-epithelialisation of the neochoanae. There is a great variability of stent material, relative size, and duration of stenting, in the literature. Most surgeons vary the duration of stent placement according to the pathology: shorter for membranous or unilateral atresia, with an average duration of six weeks; and slightly longer for revision cases (Park *et al.*, 2000). Stents serve as a nidus for infection, and so many surgeons recommend broad spectrum antibiotics for the entire stenting period in order to lessen the risk of purulent rhinorrhea and sepsis (Hengerer and Strome, 1982; Singh, 1990).

Since laser-tissue interaction causes minimal adjacent tissue damage, resulting in rapid healing and minimal scarring, it could be expected that no stents should be necessary following laser repair. Although some authors (Panwar and Martin, 1996; Illum, 1986; Tzifa and Skinner, 2001) did not use stents after laser correction of choanal atresia, and reported no increased restenosis rate in their series, these authors were treating older patients who underwent revision surgery or correction of unilateral atresia. However, a number of surgeons performing laser-assisted choanal atresia repair use stents postoperatively for a variable period of time (Healy *et al.*, 1978; Muntz, 1987; Josephson *et al.*, 1998; Pototschnig *et al.*, 2001; Meer and Tschopp, 2000; Fong *et al.*, 1999). One of the present authors (JK) does not use stenting routinely since, in his hands, the rate of restenosis is comparable whether or not stenting is used.

17.5. Fatal outcome

Yuan *et al.* (1993) described a case in which an Nd:YAG laser was used. Unfortunately, the outcome was fatal. This was believed to be due to a gas embolism caused by the nitrogen coolant which may have leaked into the tissue.

18. Conclusion

Laser-assisted, transnasal endoscopic management of unilateral choanal atresia as an elective procedure is a useful option if a laser is available to the operator.

Illum (1986) used a CO_2 laser under microscopic control in nine patients. No stent was used in the postoperative period. Normal air passage was obtained in six patients. One patient, who had coexisting adhesions throughout the entire nasal cavity after previous treatment by dilation, achieved limited air passage after one laser treatment.

Pototschnig *et al.* (2001) used the KTP laser transnasally under endoscopic control in 13 cases of bilateral and unilateral choanal atresia or stenosis. For bilateral choanal atresia, the operation was performed within the first few days after birth. For unilateral choanal atresia or stenosis, surgery was performed several weeks after birth. In all cases, an intranasal stent was inserted. These authors found that the transnasal approach provided significant benefit with a diminished risk of intraoperative or postoperative complications. Additional benefits included lower rates of restenosis. The follow-up period was three and a half years.

Tzifa and Skinner (2001) described the endoscopic repair of unilateral choanal atresia with the KTP laser, in a one-stage procedure, without stenting. Three patients with unilateral choanal atresia, aged six, nine and 38 years, were treated. Follow-up was between one and four years with all choanae remaining patent, and no dilatation was required. No surgical complications occurred.

Muntz (1987) used the CO_2 laser to correct choanal atresia via the transnasal approach. He found that some cases included septal deviation, enlarged inferior turbinates, a high arched hard palate, and other craniofacial disorders. He noted that prolonged duration of stenting appears to reduce the success rate.

The literature is full of the experiences of a number of authors. Obviously, there is no one standard method of using a particular laser, with or without stenting, in order to achieve good longterm results with no restenosis. A randomised control trial is not possible since the condition is not common, and it is unlikely that any one surgeon will ever come across a number of cases that could be entered into a trial for establishing a statistically significant outcome.

While the laser can be effectively used in unilateral cases in very young children, the present authors believe that the operation should be deferred until the age of four so that wider operating space is available. At the age of four years, the child starts schooling, and thus the cure of rhinorrhoea would be appropriate.

For bilateral cases presenting with respiratory distress, the finely balanced decision whether or not to use the laser should be taken with a competent surgical team. Alternative methods of restoring the airway quickly must always be available.

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MCQ – 31. Laser management of pathology in the posterior nose/nasopharynx

1. Nasal and nasopharyngeal recurrent respiratory papilloma
   a. Is a rare condition
   b. Is easily diagnosed with CT scan in early cases
   c. Is usually not diagnosed early, until the symptoms of obstruction appear
   d. A systematic examination of all the areas including fossa of Rosenmuller and nasopharyngeal surface of the soft palate must be carried out to exclude presence of pathological lesions.
   e. All accessible lesions should be removed with cold instrumentation since laser usage results in much scarring and stenosis

2. Laser interstitial thermal therapy ablates the tissue
   a. By vaporisation
   b. By coagulation
   c. By avascular necrosis
   d. By photosensitisation
   e. By initiating immune response

3. The *effect* of the treatment is assessed by
   a. Fibretom
   b. Magnetic resonance imaging
   c. Observing blanching of surface mucosa
   d. Observing shrinkage of tissue
   e. Symptomatic improvement

4. Bilateral choanal atresia
   a. Is managed electively within a few days of life
   b. Should be corrected before schooling begins
   c. Results in cyclical cyanosis
   d. Requires management at birth
   e. Laser is ideal to quickly restore nasal airway

5. Unilateral choanal atresia Is diagnosed
   a. At birth
   b. By passing catheter in the obstructed nostril
   c. By instilling a dye in the nostril and checking oropharynx
   d. By CT scan
   e. By symptom of anosmia on the obstructed side

6. Laser management is carried out
   a. Via endonasal route
   b. Via transpalatal route
   c. Via transpalatal and endonasal route
   d. Using microscope
   e. Using endoscope

7. In the presence of active bleeding from mucosa covering the bone,
    a. KTP laser is effective in controlling the bleeding
    b. Ho:Yag laser is effective in controlling the bleeding
    c. Decongestant is effective in controlling the bleeding
    d. Diathermy is effective in controlling the bleeding

8. Oral fistula
    a. Is common when laser is used
    b. Can be avoided by using laser in intermittent mode, and avoiding formation of char
    c. Can be avoided by periodically checking progress of bone removal by transillumination via nasopharynx
    d. By using microscope rather than endoscope
    e. By using KTP rather than HO:YAG laser

9. Restenosis is common
    a. When laser is used
    b. When tissue is devitalised due to excessive heating resulting from use of laser in continuous mode
    c. When laser surgery is not followed by insertion of stent
    d. When operated via transpalatal route
    e. When large part of atresia is bony rather than membranous

10. Stenting
    a. Causes granulations and encourages restenosis
    b. Should always be used after laser surgery
    c. Should be left in situ for six months
    d. Should be removed after six weeks
    e. May not be necessary if laser is used meticulously so as to minimise collateral thermal damage

Answers MCQ

Chapter 2:
1b, 2c, 3a, 4ae, 5a, 6e, 7ac, 8e, 9c

Chapter 3:
1e, 2bd, 3abc, 4d, 5abcde, 6a, 7abce

Chapter 4:
1d, 2a, 3bc, 4bce, 5ce

Chapter 5:
1c, 2c, 3c, 4be, 5c, 6bde

Chapter 6:
1e, 2ce, 3e, 4cd, 5abd, 6e, 7acde, 8abd, 9bcd, 10f

Chapter 7:
1abd, 2ac, 3bce, 4e, 5d, 6e, 7d, 8bd

Chapter 8:
1abce, 2cd, 3bc, 4ade, 5bd, 6bde, 7bcde, 8ac, 9be, 10acd

Chapter 9:
1ab, 2c, 3bcd, 4c, 5bd, 6ac, 7ad, 8ac, 9a, 10b, 11b, 12e, 13e, 14d, 15b, 16c, 17e

Chapter 10:
1b, 2e, 3abce, 4abd, 5c, 6bd, 7abd, 8d

Chapter 11:
1e, 2ab, 3bd, 4f, 5bcde, 6b, 7de, 8e, 9e, 10be, 11d, 12c, 13e

Chapter 12:
1b, 2c, 3a, 4abd, 5d, 6ab, 7abd, 8abde, 9e

Chapter 13:
1e, 2cd, 3b, 4b, 5e, 6e, 7bcde, 8e, 9d, 10d, 11c, 12e, 13b

Chapter 14:
1e, 2bde, 3ab, 4e, 5e, 6b, 7ade

Chapter 15:
1c, 2c, 3d, 4bcd, 5acd, 6e, 7ae, 8ad, 9bc, 10a, 11acd, 12abce

Chapter 16:
1b, 2d, 3acd, 4c, 5abce, 6ce, 7a, 8acd, 9ad

Chapter 17:
1a, 2b, 3ac, 4ab, 5be, 6a, 7be, 8bde, 9ade

Chapter 18:
1b, 2c, 3be, 4ae, 5bde, 6bc, 7c

Chapter 19:
1ad, 2acde, 3bc, 4e, 5ace, 6e

Chapter 20:
1ad, 2e, 3ac, 4b, 5d, 6bcd, 7a, 8acd

Chapter 21:
1e, 2ce, 3bce, 4ade, 5e, 6c, 7bcd, 8e, 9bcd, 10bd

Chapter 22:
1ade, 2bc, 3e, 4a, 5ad, 6ade, 7abce, 8f, 9ce, 10f

Chapter 23:
1bcd, 2a, 3e, 4b

Chapter 24:
1ac, 2cd, 3bd, 4b, 5a, 6acd, 7be, 8cd

Chapter 25:
1cde, 2cde, 3c, 4bd, 5ad, 6e, 7e

Chapter 26:
1abd, 2b, 3bcd, 4e, 5bc, 6cd, 7cd, 8acd, 9e

Chapter 27:
1bcd, 2d, 3bc, 4b

Chapter 28:
1abe, 2bcd, 3cde, 4b, 5bce, 6bde

Chapter 29:
1b, 2d, 3e, 4bce, 5d, 6e, 7ad, 8bd, 9bcd, 10be

Chapter 30:
1e, 2be, 3ac, 4e, 5bcde, 6ac

Chapter 31:
1acd, 2bce, 3bcde, 4cd, 5bcd, 6ade, 7bc, 8bc, 9be, 10ade

PRINCIPLES AND PRACTICE OF LASERS IN OTORHINOLARYNGOLOGY AND HEAD AND NECK SURGERY – 2ND EDITION

Volume II

Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery

This second and enlarged edition is built upon the success of the first edition published in 2002. From the conceptual beginning of commissioning the second edition, this work has taken three years to come to fruition. It is covered in some 67 chapters, signifying the present, emerging and future trends in medical applications of lasers. The chapters have been contributed by some 59 internationally recognised authorities who were recruited for their expertise in a particular laser topic. The pro forma has undergone some metamorphosis. While the sectional demarcation retains the well-trodden path of anatomical delineation, the chapters have been rearranged along the familiar disease or dysfunctional notations used in everyday practice. Each chapter is sumptuously presented with high-quality colour photographs. The Multiple Choice Questions (MCQ) at the end of each chapter provide a simple recall test and prompts revision where necessary. A continuing support is provided by the ubiquitous website dedicated to the book title.

THE EDITORS

Mr V. OSWAL

Mr Oswal's interest in the laser technology, dating back to the seventies of the last century, culminated in the acquisitions of the Coherent® CO2 laser in 1981 with funds raised by public appeal. The fledgling technology required much pioneering work with bench experiments to evaluate laser biophysics for its clinical applications. He established a number of laser training courses in the UK and internationally and has been awarded with honorary membership of Otolaryngology Associations of many countries. He has written and presented widely on various laser topics. He has chaired laser sessions at the international conferences organised in countries all over the globe. He is an Associate Editor of Lasers in Medical Science, past Editor-in-Chief of ENTNews and member of the editorial board of a number of laser journals.

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M. Remacle

co-editors
S. Jovanovic
S. Zeitels
J. Krespi
C. Hopper

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Second enlarged edition

edited by V. Oswal and M. Remacle

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Volume II

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Chapter 32

Lasers in otology: General considerations

V. Oswal

1. Introduction

Surgical procedures on the ear are widely undertaken with cold instruments, which cause tissue ablation by transmitting mechanical energy. Some instruments, such as the drill, have additional vibratory energy. In order to achieve ablation without these unwanted effects, several alternative energy modes have been used. DiBartolomeo and Ellis (1980) have given an excellent account of these in an article on the argon laser in Otolaryngology. Clarke (1973) used electrocautery to excise exostoses in the external auditory canal. Mülwert and Voss (1928) used ultrasonic therapy externally for the treatment of otosclerosis and tinnitus. Krejci (1952) exposed the mastoid surgically, and applied the ultrasound beam directly to the inner ear for the treatment of Ménière's disease, thus aiming to destroy the vestibular function. However, treatment with ultrasound did not prevail since it lacked the precision required for selective ablation. Selective cryosurgical destruction also failed to show any significant advantages.

A large part of the operative procedure on the ear involves gross bone removal, which is still undertaken using conventional methods. The laser provides a form of energy that can be used for undertaking certain steps of the procedure where an extreme degree of finesse is required, or where conventional procedures produce gross results with therapeutic as well as unwanted effects. The spread of laser energy can be limited by preselecting parameters for tissue ablation with a precision that was not hitherto possible.

2. Review of the literature

Lasers were introduced in the surgical practice in otolaryngology in 1970s. As we enter the second decade of the twenty first century, laser applications in ear surgery are still not widespread. They represent a departure from conventional, established, cold-instrument surgical techniques. As such, a prospective laser otologist needs to address some of the basic issues involved in the application of lasers in ear surgery. A good starting point is a review of the literature. However, it is necessary to appreciate that, although published works are very useful, they are accounts of the expertise of individuals or team of surgeons and not necessarily a means of enhancing the operator's capability of producing satisfactory results.

The earliest laser to be used on the ear was the ruby laser on the inner ears of pigeons (Stahle and Höberg, 1965). These authors later used the argon laser on the organ of Corti of guinea pigs in order to produce superficial changes in the stria vascularis without affecting the otic capsule (1972). At low intensities, the argon laser wavelength penetrates through the bone without altering it. Thus, it can be used to devitalise extensions of cholesteatoma within the cell spaces of the mastoid bone. At high energy, it vaporises the bone, and has been used to undertake fenestration of the footplate in otosclerosis. The red pigment of the blood also selectively absorbs argon and the tissue can be blanched before removal, thereby increasing surgical precision. The

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non-contact method of delivery ensures vibration-free tissue ablation.

Sataloff (1967) used the Nd:YAG laser to treat the otosclerotic stapes footplate. However, it was necessary to coat the footplate with copper sulphate – which is toxic to the inner ear. Kelemen *et al.* (1967) used pulsed ruby and Nd:YAG lasers on the inner ear of mice, but these produced massive haemorrhage. Wilpizeski *et al.* (1972) used the argon laser to irradiate the semicircular canals of monkeys to selectively reduce labyrinthine function. However, these various experimental data lacked the consistency necessary for clinical application.

Escudero *et al.* (1979) used the argon laser in tympanoplasty to adhere the temporalis facia to the margins of the eardrum by means of 'spot welding'. However, it was Perkins' report (1980) regarding the use of the argon laser to create a small fenestra stapedotomy that finally established its suitability for clinical use. DiBartolomeo and Ellis (1980) reported the use of the argon laser for reconstructing soft tissue and ossicular deformities. They reported the application of the argon laser in 30 patients with a range of pathology: eardrum grafting, control of stapedial artery bleeding, middle ear adhesions, myringotomy, stapedectomy, osteoma of the external canal, and sculpturing of the ossicles.

According to DiBartolomeo and Ellis (1980), the somewhat erratic application of lasers in otology by modern otologists stems from the limitations of earlier forms of energy. However, there are also some practical issues contributing to their slow introduction.

The use of the laser aims to improve results and reduce postoperative morbidity. Their safety and the acceptable rate of complications are additional and perhaps more important factors. To this end, the onus is on the operator to identify the objectives, select the pathology, use the laser as an additional tool, assess the results and compare them with conventional methods.

3. Selection of the appropriate laser wavelength

The choice of laser for most surgical procedures in the ear is dictated by the availability of a particular wavelength in the ENT department for applications in other ENT regions. The effects of various laser wavelengths on the tissue, and in particular, the spread of thermal damage in the surrounding tissue are not comparable. Fibre transmissibility is another factor that may influence the application for certain indications. Individual enthusiasm for a new technology may be the final determining factor influencing individual preference. What is certain is that the otological laser application should not be undertaken lightly. The reasons for using the laser in certain ear conditions must be precisely stated, the objectives identified, and the outcome verified. This chapter covers the general principles involved in the application of lasers in ear surgery. The other chapters in the section cover clinical applications in a variety of ear pathology.

CO_2, KTP and argon lasers have all been used in ear surgery. The new diode laser operates in the infrared region, emitting at 810, 940 and 980 µm, depending on the model, and is fibre-transmissible. Its use in otology is sporadic. Chapter 2, covers the varying tissue effects of these lasers in detail. This chapter covers the differences in their otological applications. The argon and KTP lasers can be grouped together since they are similar in most respects. They emit in visible part of the spectrum. For convenience, they will be referred to as visible lasers in the following paragraphs, as opposed to the invisible CO_2 laser which operates in the infrared region and therefore requires an aiming beam.

4. Delivery of energy to the pathological tissue in the ear

The CO_2 laser is not transmissible via an optical fibre. The micromanipulator attached to the microscope guides the beam to the target tissue. The 'joy stick' can move the beam within the visible operative field. However, if the tissue to be ablated extends beyond the operative field, then the microscope must be repositioned. Repositioning of the microscope with the attached articulated arm is rather cumbersome, but this limitation can be very quickly overcome by an accomplished surgeon. In contrast, the delivery of visible lasers via the optical fibre of a handpiece, independent of the microscope, increases the manoeuvrability of the equipment, which is useful when treating an awkwardly situated pathology. In Chapter 34, John Hamilton has tackled this issue head on and used the KTP laser for 'Functional Orthogonal Cholesteatoma Laser Surgery'. The KTP laser beam is reflected from the surface of a metal mirror and directed on to the cholesteatoma covering the medial surfaces of the ossicles to devitalise it.

5. Alignment of the aiming beam

The CO_2 laser beam is invisible and thus requires superimposition of the aiming beam. Theoretically, this requirement introduces a lack of precision in the use of this laser.

5.1. Spot size of the HeNe beam

The spot size of the HeNe beam is static and bears no correlation to the spot size of the therapeutic CO_2 laser beam.

5.2. Location of the HeNe beam

The visible aiming beam may not be precisely in the centre of the CO_2 laser beam. The major part of the CO_2 beam may be on one side or other of the visible beam.

5.3. Loss of alignment

Some precision of the alignment may also be lost due to movement of the articulated arm while the microscope is being adjusted. This loss of alignment is particularly important in footplate surgery for otosclerosis. Therefore, the alignment is rechecked by striking a wooden spatula just before the footplate strike. In contrast, emission of the KTP and argon wavelength in the visible spectrum obviates the need for this, and overcomes any problems associated with the alignment of a separate aiming beam.

6. Absorption of the laser wavelength

The CO_2 laser is absorbed in water and thus all the energy is spent at the interface, with very little conduction. This aspect of the CO_2 laser is particularly useful in footplate surgery. As a stapedotomy is created, the perilymph is exposed and the CO_2 energy absorbed. Thus, there is no conduction of energy to the stria vascularis and, therefore, no inner ear damage. In contrast, visible laser energy (KTP and argon) passes through the perilymph without being absorbed. Since visible energy is absorbed by pigment (haemoglobin in the blood) in the stria vascularis, the possibility of inner ear damage exists. However, clinical experience has not borne out this theoretical consideration. The most likely explanation for the lack of inner ear damage is that the beam guided by the optical fibre diverges immediately upon exit, and thus loses power density. Any slight energy that may be absorbed does not result in thermal damage to the inner ear.

7. Conduction of thermal energy to the inner ear

There is a possibility of thermal energy being conducted to the saccule while diseased mucosa covering the footplate or promontory is being ablated, and also during stapedotomy perforation. In fresh cadavers, Ricci and Mazzoni (1985) used thermocouples to measure the rise in temperature following stapedotomy and coagulation of mucosa on the promontory with argon laser. The maximum rise was 3.5°C, which was considered safe, particularly compared to the thermal stimulation caused by routinely performed conventional caloric testing for vestibular disorders.

On the other hand, Schreiner and Vollrath (1983) noted rapid depression of compound action potential (CAP) following argon laser stapedotomy, taking up to 40 seconds for full recovery. No permanent loss was recorded. Thus, vestibular disturbance following laser stapedotomy may be due to a transient rise in the temperature of the saccule, leading to thermal labyrinthitis.

Nomura *et al.* (1995) irradiated the semicircular canals of guinea pigs with argon laser (1-1.5 W, 0.5 seconds). They noted a charred area on the bone, with or without perforation. The semicircular duct showed tearing and shrinkage of the trabecular meshwork immediately after irradiation. Therefore, it is obvious that, when a laser is used on the promontory for the removal of hyperplastic mucosa, granulation or scar tissue, the possibility of the potential heating of inner ear structures should not be overlooked.

8. Access to the surgical site

The access to a surgical site with the CO_2 laser is somewhat limited due to the need for manipulation of the microscope. However, the CO_2 laser offers a considerable advantage over fibre-guided visible lasers in most situations. The view of the target is totally unrestricted since there is no carrier handle (an optical fibre) for the beam delivery. The CO_2 laser beam also remains collimated and thus retains the power density at the focal length of the chosen objective (the reflecting mirror on the manipulator must match the focal length of the objective used).

The concentration of energy of the fibre-delivered visible laser is maximum at the exit point. Therefore, in order to create a perforation, the fibre tip must be almost in contact with the footplate. The view of the operation site is thus somewhat restricted by the presence of the fibre and its carrier cannula.

9. Haemostasis

The CO_2 laser is a poor haemostat. Defocusing the beam on the micromanipulator can increase its haemostatic properties. Visible lasers are well absorbed by the pigment and therefore offer excellent haemostasis. Vascular or inflamed tissues can be blanched with the fibre tip held at a distance in order to diffuse the beam and strike the tissue, thus enhancing direct thermal coagulation prior to dissection or vaporisation.

10. CO_2 laser accessories

The CO_2 laser, the most widely available wavelength in ENT departments, is maximally absorbed in water. Application to bone, which has a poor water content, results in charring rather than vaporisation. The standard spot size is too large for confined spaces where vital structures are situated close together. A number of these issues has been resolved with the introduction of the various accessories described in Chapter 4.

In this section, we have attempted to provide an overview of laser experience in otology, together with a detailed description of laser usage in selected ear conditions. This work is by no means complete. As further refinements are introduced, new otological applications will be reported. However, as in other areas of surgical practice, no amount of refinement of equipment can replace the surgical skill of the operator, and laser applications in otology are no exception.

11. Benefit and risk issue in laser ear surgery

For any practicing otologist, surgical procedure on the ear is second nature. Use of laser as a complimentary instrumentation does require additional training, but laser as an adjunct surgical modality does not *inherently* introduce any additional risk to the patient. CO_2 laser stapedotomy is, in fact, so automated that all that is asked of a surgeon is to decide the size of the fenestra, set the machine up accordingly, identify the target (in this case, a stapes footplate), aim and shoot! A clean single shot stapedotomy fenestra is achieved, as described in Chapter 36.

In cholesteatoma surgery, according to Hamilton (2010) the fibre-guided laser significantly improves complete eradication of the disease and also preserves the integrity of the ossicular chain in a 'systematic manner' which is both 'safe and of benefit' to the patient (Hamilton, 2005) (Chapter 34).

Facial nerve palsy

In every middle ear surgical procedure, the facial nerve remains vulnerable to damage, be it with cold instrumentation or the laser. The chapters covering the various clinical applications describe in detail the precautions which should be taken to preserve the integrity of the facial nerve during laser ear surgery.

Mills *et al.* (2003) investigated the temperature gradient in the facial canal in preserved human temporal bones during a stapes procedure, using a KTP laser or microdrill. Their finding was that the temperature rise was significantly greater for KTP laser when compared to the microdrill. They concluded that the heating during laser surgery causes oedema of the facial nerve leading to facial paralysis.

Any laser surgeon will know that the laser should not be used in the close proximity of the course of the facial nerve. If the facial nerve is directly injured with the laser, the paralysis will be immediate. On the other hand, if findings of Mills *et al.* (2003) are equated to an *in vivo* event, then the paresis, progressing in some cases to a complete paralysis would ensue within 24-48 hours of the laser usage, but no later.

Delayed facial palsy: Herpes simplex virus activation

Shea and Ge (2001) reported 11 cases of delayed facial palsy (DFP) from five to sixteen days (mean eight days) postoperatively following conventional stapedectomy. In five cases, there was an identifiable cause such as bare facial nerve or an overhang, but in the remaining six patients, aetiology was not clear. However, reactivation of herpes simplex virus was considered. Serological tests did show elevated anti-varicella antibody titre. They concluded that mechanical irritation of the facial nerve or chorda tympani may have triggered the activation of the latent herpes virus, resulting in delayed facial paralysis. In one of the initial six patients who had undergone a revision stapes surgery, it was possible to prevent reactivation with a course of acyclovir.

According to Gianoli and Kartush (1996), herpes simplex virus and varicella-zoster virus are reactivated during times of stress. Stimulation during trigeminal nerve surgery may reactivate herpes simplex with manifestations in the sensory distribution of the trigeminal nerve. In their case of delayed facial nerve palsy, patient had undergone translabyrinthine resection of intracanalicular acoustic neuroma. Following surgery, the patient developed otalgia and classical vesicles in the ipsilateral ear canal and also on the ipsilateral buccal mucosa. Progressive facial palsy ensued a week after the surgery. Serologic evaluation confirmed the diagnosis of herpes zoster oticus. Based on the case report, they advocate serological investigation and antiviral management in delayed facial palsy following any ear surgery,

Prevention of the reactivation has been demonstrated in placebo-controlled trials by using prophylactic acyclovir (Gianoli and Kartush, 1996).

In a cohort of 348 patients undergoing vestibular schwannoma surgery Franco-Vidal *et al.* (2004) reported eight patients developing delayed facial nerve palsy more than 72 hours postoperatively. A serologic search for specific anti-herpes simplex viruses type 1 and 2 (HSV-2) and varicella zoster virus (VZV) antibodies at the onset of DFP and 2 weeks later were possible in three cases. The tests revealed either a high level of anti HSV or VZV antibodies at the time of onset or a dramatic increase in anti-HSV or anti-VZV antibodies between the two samples, strongly suggesting an HSV or VZV reactivation. Based on their series, they advocate immediate steroid and acyclovir administration to obtain total recovery.

De Stefano *et al.* (2009) reported occurrence of facial nerve paralysis some eleven days postoperatively following an uneventful canal wall-down mastoidectomy. Viral screening for Herpes Virus type 1 confirmed the viral aetiology of the delayed facial paralysis. They rightly advocate that if delayed facial palsy occurs no earlier than 72 hours postoperatively following an uneventful ear surgery, then viral reactivation should be suspected, serological investigation and antiviral therapy should be initiated.

Eskander *et al.* (2010) reported three cases of delayed facial nerve paresis following the use of KTP laser in cholesteatoma surgery. Intraoperative facial nerve monitor did not identify any injury and the KTP laser was not used directly on the nerve. Facial palsy ensued seventh to ninth day postoperatively. The facial palsy resolved completely between four to seven weeks after the onset of the paralysis. They state that, while the KTP laser during cholesteatoma surgery has been shown to decrease residual disease (Chapter 34) it may however cause a temporary, delayed, mild facial nerve paresis.

Ng and Maceri (1999) report two cases of delayed facial palsy, five to seven days postoperatively, following KTP laser stapedotomy. Tapering courses of oral steroids resolved the palsy. They state that the presentation and resolution of the facial palsy is similar to other types of delayed facial palsy resulting from non-laser techniques of stapes surgery. They postulate that the aetiology of delayed facial palsy was viral neuritis from reactivation of dormant virus within the facial nerve, initiated by thermal stress of the KTP laser.

Their report merely confirms that while the facial nerve can suffer delayed palsy following KTP laser ear surgery, it is not any more susceptible to palsy just because the KTP (or any other) laser was used.

Based on the above, it is prudent that, in all cases of delayed facial nerve palsy occurring more than 72 hours following ear surgery, a viral reactivation should be considered, prompting serological investigations and antiviral treatment, irrespective of the type of surgical instrumentation used.

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MCQ – 32. Lasers in otology: General considerations

1. The two most commonly used lasers for ear surgery are:
    a. Nd:YAG and Diode
    b. Diode and KTP
    c. CO_2 and KTP
    d. KTP and Argon
    e. Er: YAG and CO_2

2. Alignment of the He-Ne and the CO_2 laser for stapes surgery must be checked
    a. At the beginning of the operating session
    b. At the beginning of stapes surgery
    c. Just before using it for stapedotomy
    d. Just before using it on stapes tendon
    e. Just before using it on posterior crus

3. While using the laser on the promontory, heat transmission to the inner ear structures
    a. Is a possibility
    b. Can occur but without any injurious effects
    c. May result in permanent damage to the inner ear
    d. Is a possibility and therefore laser should never be used on the promontory
    e. None of the above

4. Facial paralysis due to heat transmission from the laser occurs
    a. 72 hours or later after the operation
    b. Within 72 hours
    c. Immediately after surgery
    d. Never occurs

5. Delayed facial nerve paresis or paralysis after more than 72 hours is due to
    a. Heat transmission to facial nerve
    b. Continuing laser action after surgery
    c. Reactivation of herpes zoster virus
    d. Usually results in complete resolution
    e. Should be investigated with serological testing for viral antibodies

6. Reactivation of herpes zoster virus is
    a. More common when KTP laser is used
    b. More common when CO_2 laser is used
    c. More common when microdrill is used
    d. Not dependent on the instrumentation used

7. Acyclovir should be prescribed for
    a. All cases of delayed facial paresis or palsy
    b. All cases of facial palsy irrespective of when it occurred
    c. As well as oral steroids for delayed facial paresis or palsy
    d. Only if serological testing is positive for herpes zoster virus
    e. Empirically even if serological testing is negative

Chapter 33

An overview of lasers in otology

V. Oswal and P. Garin

1. Introduction

The standard surgical techniques for ear microsurgery have evolved over time and are well established. Although it must be acknowledged that ear surgery can be performed successfully without the use of lasers, a review of the literature shows a number of reports on the application of laser technology in external, middle, and inner ear lesions. This chapter provides an overview of laser usage in otology. The detailed laser management of cholesteatoma, glue ear, and otosclerosis is covered in subsequent chapters.

2. External auditory canal

2.1. Vascular lesions of the external auditory canal

Parkin (1990) reported the removal of haemangiomas and telangiectasias in the external auditory canal (EAC) with an argon laser delivered with a hand-held otoprobe. The power rating was 2 W, in the continuous or pulsed mode. Laser coagulation of superficial haemangiomas and telangiectasias in the EAC gives excellent results, although after healing, the skin becomes thinner and more fragile than normal.

Larger and deeper haemangiomas require a combined management strategy. Initial embolisation is followed by interstitial laser coagulation, surgical removal, and reconstruction of the defect. The Nd:YAG laser, with its deep scatter, appears to be the laser of choice, but other fibre-transmissible lasers such as the KTP and diode are equally suitable.

2.2. Aural polyps and granulations in the external auditory canal

Conventional removal of granuloma and polyps in the EAC can be notoriously haemorrhagic. The laser provides an excellent means of managing such conditions. Following biopsy, laser vaporisation allows relatively bloodless removal, and provides clear visualisation of the underlying tympanic membrane defect and any associated cholesteatoma (Parkin, 1990).

2.3. Stenosis of the external auditory canal

Membranous stenosis of the EAC can easily be excised by vaporisation using the CO_2 laser (Parkin, 1990). Fibrotic stenotic areas caused by scar tissue may require grafting after laser vaporisation. Osseous atresia of the external ear canal is resistant to laser vaporisation because of their dense ivory-like texture. Exostosis adjacent to the tympanic membrane is amenable to CO_2 laser removal (Fig. 1), and avoids transmission of mechanical trauma to the middle and inner ear.

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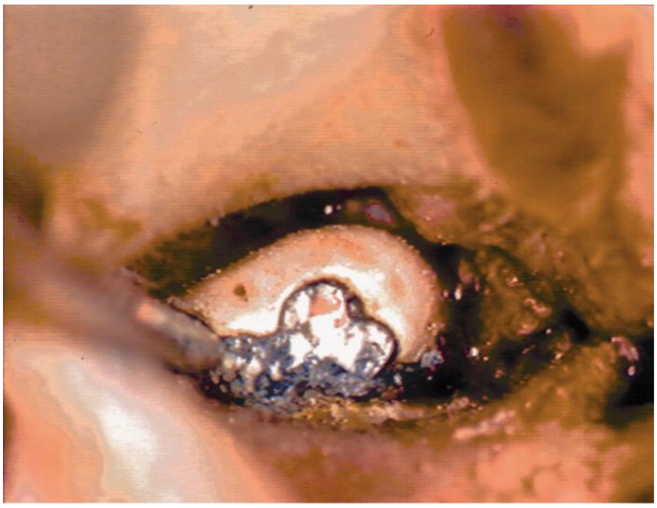

Fig. 1. Removal of exostoses close to the tympanic membrane with the CO_2 laser without instrument contact. (Courtesy S. Jovanovic)

However, it is quicker and easier to remove larger, accessible exostoses in the lateral portion of the EAC using a drill.

Kumar *et al*. (1997) reported the use of a KTP/532 laser for the treatment of hyperplastic stenosis of the external auditory meatus (EAM) resulting from chronic otitis externa. The KTP laser was used in eight patients (ten procedures) under general anaesthesia to vaporise squamous epithelial hyperplasia and fibrosis of the external auditory meatus, until healthy dermis was encountered. All patients were rated as having severe stenosis (>66% occlusion of the EAM). A 200μm fibre is recommended as it gives a small spot size for precise surgery. A power setting of 2 W was used with continuous exposure. Vaporisation begins in an antero-posterior direction on a broad front without creating narrow channels, in order to avoid inadvertent entry into the middle ear. Occasionally, the level of the tympanic membrane is difficult to assess on account of gross thickening resulting from chronic otitis externa. During vaporisation, attempts are made to identify the tympanic membrane in the anterior part of the stenosed canal, in order to avoid trauma to the ossicles. No grafting is necessary since regeneration of the healthy epithelium takes place in the deeper layers of the skin. Using the laser, an average operating time of ten minutes provided a quick surgical technique. Two cases resulted in perforation of the tympanic membrane, one of which healed rapidly, while the other was patent 12 months postoperatively. None of the patients showed restenosis as much as preoperatively (>66%), although two had minor (0–33%) and one moderate (33-66%) restenosis.

2.4. Debulking

Debulking of large, inoperable EAC carcinoma, causing bleeding and recurrent otorrhoea, can be performed using the CO_2 or visible lasers (Parkin, 1990).

2.5. Laser reshaping of cartilage

Carbon dioxide laser assisted cartilage reshaping for otoplasty reported by Ragab (2010) is not to be confused with laser cartilage reshaping described in Chapter 63. Ragab used CO_2 laser for an open surgical procedure to vaporise the perichondrium and partial thickness of the medial surface of auricular cartilage. Two parallel laser incisions on scaphal and conchal lines were performed and the cartilage was fixed with absorbable Vicryl mattress sutures.

We reserve the term laser cartilage reshaping strictly to a closed procedure where no skin incision is taken. The basic science involves temperature-dependent cartilage stress relaxation during laser application resulting in stable shape changes and is fully described in Chapters 61 and 63.

Laser cartilage reshaping, first described in the 1990s, has a potential use for the otolaryngologist. In septoplasty, the deformed septal cartilage may be reshaped *in vivo* with the thermal energy of the lasers. The flat 'bat ear' may be reshaped with laser strikes. In rhinoplasty, cartilage grafts may be moulded as required. The laser action in remodelling is based on its photothermal energy. The reshaping occurs as a result of relaxation of internal stress of the cartilage using low level laser energy. The rise in temperature to about 70°C influences a physical-chemical change, altering the sensitive ratio of bound-to-free water, associated with proteoglycan molecules (Jones *et al.*, 2001).

Various wavelengths have been used for cartilage reshaping. The CO_2 laser was the first wavelength used for reshaping, followed by Nd:YAG and Ho:YAG lasers. The variation in their effect is thought to be due to their variable penetration depths.

Gorgu *et al.* (2000) used Er:YAG laser on cartilage reshaping *in vitro* and compared the results with scalpel stripping and suture holding. Changes in the shape of cartilage were evaluated at 15 minutes, and Day 1, 4, and 10. The majority of cartilage in the scalpel-stripped group returned to the initial shape by Day 10, whereas the laser-stripped cartilage showed progressive warping day by day. Almost all cartilage formed a circle by Day 10. They noted that Er:YAG laser enhanced cartilage warping by a mechanical effect of stripping and a thermal effect of laser radiation. Velegrakis *et al.* (2000) used CO_2 laser beam for *in vitro* cartilaginous tissue remodelling. Straight cartilage samples were removed from the ears of 21 rabbits. The perichondrium was removed and the cartilage was exposed to the CO_2 laser at an output power of 3 W, a spot diameter of 2 mm, and an exposure time of 0.5 second. The remodelled cartilages and control samples were implanted into the rabbits' backs and retrieved 6 to 12 months later. Histological and morphological analysis showed that the irradiated cartilages retained both their shape and their viability.

Jones *et al.* (2001) used Ho:YAG laser with a fluence of 2 J/cm^2, delivered with pulse rate of 20 Hz and a spot size of 1.1 mm diameter to treat the cartilage, *in vivo*, of two-month-old porcine ears. Although initially all treated cartilages showed changes in the shape, the result did not last. The auricular cartilage eventually regained its shape, the duration was dependent on the laser parameters used. None of the treated cartilages retained altered shape after 14 days.

Although earlier work showed that remodelling of the cartilage was a viable proposition, the new shape did not last and the cartilage reverted to the initial shape within 14 days (Jones *et al.*, 2001).

In the past decade, much work has been undertaken to overcome this problem. Laser cartilage reshaping has now been refined to the extent that it is being used in clinical setting. Section IXB has been devoted to this subject, and covers the basic science of laser cartilage reshaping and its clinical application for correction of Bat ear deformity as well as nasal cartilagenous septal deviation.

3. Tympanic membrane lesions

3.1. Epidermoid cysts of the tympanic membrane

Using conventional instruments, such as hooks and picks, bleeding often obscures the field and makes complete removal of these cysts difficult. One of authors (PG) has used the CO_2 laser to vaporise small epidermal cysts which sometimes appear in tympanic grafts after myringoplasty or tympanoplasty. From January 1996 to January 2001, 31 patients were treated under local anaesthesia, as an office-based procedure. The CO_2 laser energy was delivered with a micromanipulator. The setting was as follows: 1-3 W in the continuous mode, an exposure time of 0.05 seconds, a spot size of 200 μm. Single strikes were used to vaporise the superficial layers of the cyst and the contents of the cyst were removed with suction, resulting in a marsupialisation of the cyst. The procedure was bloodless, with excellent healing. There was no perforation of the tympanic membrane and recurrence was low (3% with a mean follow-up of seven months).

4. Middle ear cleft

Initially limited to work around the stapes, the use of the laser has been expanded to virtually any middle ear procedure.

4.2. Laser-assisted myringoplasty

4.2.1. Perforations of the tympanic membrane

Both visible and invisible lasers are useful for promoting the healing of persistent traumatic perforations of recent origin as well as small residual central tympanic defects after myringoplasty in chronic middle ear diseases (Fig. 2). The mucocutaneous junction at the rim of the perforation is excised with several single strikes of a laser at low power, for example, the CO_2 laser, 1 W, 50 msec, delivered via a laser otoscope or micromanipulator (Figs. 3 and 4). The procedure is bloodless and avoids any inadvertent movement of the ossicular chain, associated with conventional methods (Parkin, 1990). In selected primary and revision cases of chronic middle ear disease with small central perforations, the success rate in closing the perforation after CO_2 laser treatment was over 80% (Fig. 5; Jovanovic, personal communication). In small atrophic segments of the tympanic membrane, CO_2 laser vaporisation appears to promote healing with normal looking tympanic

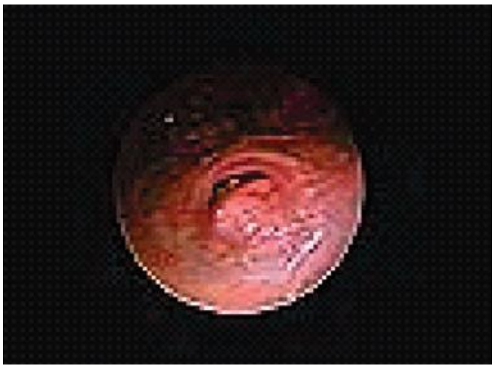

Fig. 2. Small tympanic defect in the posterior inferior part of the tympanic membrane. (Courtesy S. Jovanovic)

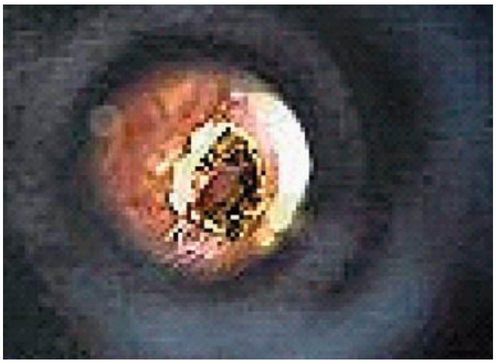

Fig. 3. Vaporisation of the edges of the perforation with the CO_2 laser. (Courtesy S. Jovanovic)

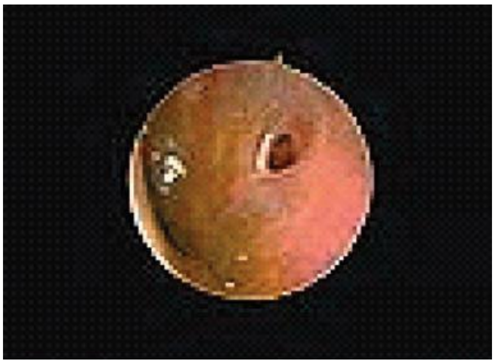

Fig. 4. Perforation on the 6th postoperative day. (Courtesy S. Jovanovic)

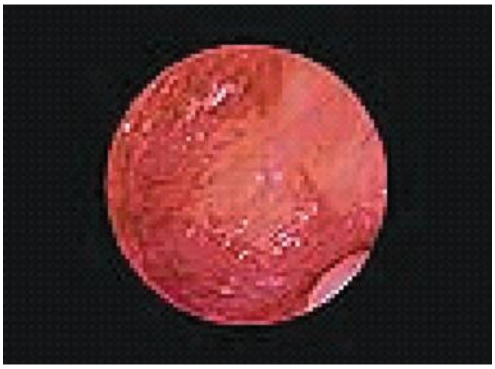

Fig. 5. Closure of the perforation of the tympanic membrane without residuals of atrophic scars six weeks postoperatively. (Courtesy S. Jovanovic)

membrane. However, retraction pockets in the postero-superior part of the eardrum should not be vaporised, as the laser could damage the underlying ossicular chain, since there is no fluid in the middle ear and the bottom of the retraction pocket may be adherent to the ossicles.

4.2.2. Graft-welding of tympanic membrane defects

In animal experiments, the thermal energy of the laser has been used to weld fascia grafts in myringoplasty (Hanna *et al.*, 1993). Argon (McKennan, 1990) and KTP (Pyykkö *et al.*, 2000) lasers have been used in myringoplasty in humans. Temporalis fascia or tragal perichondrium is harvested as usual. Myringoplasty is carried out using a transcanal approach. The middle ear is filled with saline-soaked gelfoam and the graft is placed under the remnants of the tympanic membrane. It is then 'spot-welded' with the laser, with a power setting of 0.2-1.5 W, depending on the distance between the fibre tip and the tympanic membrane. The low energy setting avoids thermal damage and charring in the graft and in the remnants of the tympanic membrane. The size of the perforation varied from subtotal to small anterior perforation, and tissue welding was successful in 29 of 30 cases with the argon laser, and in ten of 12 patients with the KTP laser.

4.2.3. Medialisation of the malleus

In some myringoplasty cases, medialisation of the malleus impedes placement of the graft. Retraction of the malleus may be due to scar tissue between it and the promontory, even if the ossicular chain is intact. Saeed and Jackler (1996) report the use of the KTP laser to sever the scar tissue and release the malleus. Laser amputation of the distal third of the handle of the malleus 'lifts' it further, so that a graft can be placed deep in it. This procedure is completely free of any mechanical trauma to the ossicular chain, common with conventional methods.

4.3. Laser-assisted ossicular surgery

Sands and Napolitano (1990) reported the case of an eight-year-old girl suffering from deafness. At operation, the malleus was found to be fixed, and the head was deformed and larger than normal. There was a bony spur projecting from the posterior bony wall of the canal. The argon laser, at 7.5 W power and a one-second burst, was used intermittently on the projecting bone. Charring was removed between the strikes. Audiometry confirmed improvement in hearing consistent with the operative findings.

Fixation of the malleus in the attic (malleus head fixation) usually requires a malleus nipper, a rather large and crude instrument which invariably causes gross movement of the remaining ossicular chain. Laser vaporisation of the malleus neck or vaporisation of the sclerotic foci around the head frees the chain without any gross movement (McGee, 1990; Sands and Napolitano, 1990; Jovanovic *et al.,* 1997a,b).

Lasers have been used to remove tympanosclerosis affecting the ossicular chain, without excessive manipulation of the ossicles. For this indication, the CO_2 laser is appropriate. It is not advisable to use the Er:YAG laser because of possible inner ear damage due to induced shock waves.

In some cases of ossiculoplasty, the initial improvement in hearing deteriorates. This may be due to displacement of the ossicles, or due to fibrosis in the tympanum restricting the movement of the ossicles. In long-standing cases, there may even be tympanosclerosis or fixation of joints. Laser technology can be of much use in such conditions in a variety of ways.

Laser myringotomy for diagnostic purposes can be undertaken as an office procedure under local anaesthesia. Pre- and postoperative audiometry results can be evaluated and correlated with the findings of laser myringotomy. Both the surgeon and the patient are thus forewarned as to the definitive management required to restore hearing.

Lasers are most useful for releasing prostheses and restoring mobility by vaporising fibrous strands. No mechanical tugging is involved and therefore the integrity of the conductive mechanism is not jeopardised. The transmission of mechanical energy to the inner ear, associated with mechanical methods, is also avoided.

Displaced and unstable prostheses can be repositioned and welded together in order to achieve stability. The possibility of laser-assisted ossicular reconstruction has been studied *in vitro* (Park and Min, 2000). In order to increase the stability of reconstructed ossicular chain, welding of human ossicles and synthetic ossicular prostheses was performed using CO_2, Nd:YAG and argon lasers. Direct use of lasers on ossicles and prostheses is not recommended, because the surface could easily be destroyed. It is necessary to use solder, melted at a relatively low temperature by the laser energy. Several proteinous materials were tested. Commercial fibrin glue showed the best bonding strength and adhesiveness in laser welding. At the time of writing, the advantages of laser welding compared to glues in current use have not been demonstrated.

4.4. Removal of inflammatory disease

The chronic ear disease usually results in the formation of hyperplastic mucosa, granulations, cholesteatoma, etc. Such pathology usually obscures landmarks which may also be distorted due to previous surgery. Conventional mechanical clearance results in intraoperative bleeding that obscures landmarks. The removal of pathology entails tug and pull manoeuvres, which can lead to the mobilisation of stapes, disarticulation of ossicles, and possible inner ear damage. Cases where granulations and hyperplastic mucosa completely obscure the stapes area are most at risk from cold-instrument surgery.

Thedinger (1990) reported the use of the KTP laser in 103 cases of chronic ear disease following tympanoplasty with mastoidectomy. The pathology included granulations, hyperplastic mucosa, adhesions and sclerotic patches, and cholesteatoma. Although the pathology affected all areas, of particular interest were those of the stapes, footplate, round window niche, and facial nerve.

Using the KTP laser, the energy was delivered via a 400-μm optical fibre or a micromanipulator. The fibre delivery provides feedback and the tip can be used to 'feel' the disease process prior to vaporisation. The micromanipulator allows unrestricted delivery of the energy to the disease site. Both methods are appropriate and are sometimes used in combination. Typical KTP laser parameters were 1-3 W power and 0.2 second duration in the continuous mode.

The laser is used to cut, vaporise or coagulate, as required. Since the mucosa contains pigment and the ossicles do not, the energy is preferentially taken up by the mucosa, which is easily ablated without any mechanical trauma to the ossicles.

Where necessary, part of the ossicle can be vaporised to improve access to the disease site. Any excessive thermal effects are reduced by using intermittent exposure and irrigation with water. Since the KTP laser energy is not well absorbed by water, a thin layer is useful to dissipate the heat and still have adequate energy absorption by pigment-containing mucosa. When dealing with disease close to vital structures, single shots at low power levels are used in order to minimise the spread of energy to the inner ear or facial nerve.

Thedinger (1990) experienced a reduced rate of recurrent disease and in some cases, complete removal of cholesteatoma was achieved. Chapter 34 covers the application of the KTP laser in cholesteatoma cases in detail. The CO_2 laser with a scanner system (*e.g.*, SurgiTouch™) is also particularly useful in such procedures, since it limits deeper thermal spread.

4.5. Vascular lesions of the middle ear

Glomus tympanicum tumour (paraganglioma) (Fig. 6) is a highly vascular tumour and arises from the paraganglion situated on the promontory. Laser-assisted surgical management consists of reduction of overall vascularity by photocoagulating peripheral feeding blood vessels. This is followed by shrinking the tumour with laser strikes and removal by vaporisation. The argon or KTP lasers, which are well absorbed by the pigment of the highly vascular tissue, are most suitable for this procedure (Figs. 7, 8 and 9).

The Nd:YAG laser is also useful on account of its coagulation effect, due to deep scatter. Robinson *et al.* (1993) reported the case of a 60-year-old female patient suffering from glomus filling the hypotympanum inferiorly up to the horizontal portion of the facial nerve superiorly. Nd:YAG laser energy was delivered via a 400-µm flexible fibre, held 2-3 mm superficial to the tumour surface. Single shot application at 1 W for 1-2 seconds was increased to 5-6 W power. At this power level, the tumour contracted in the centre and shrivelled so that the margins were drawn into the centre of the operative site. Vaporisation was undertaken little by little. Although the tumour was wrapped around the incudo-stapedial joint, no manipulation of the joint was necessary because the vaporisation effectively removed the tumour from the site. Intraoperative blood loss was 50 ml. Facial nerve function and vestibular function were completely preserved. There was an initial deterioration in hearing, thought to be due to hair cell damage while removing the tumour from the round window niche. However, hearing returned to preoperative levels within 18 months. The patient experienced constant high-pitched tinnitus, but the severity of this lessened over a six-month period. This case demonstrates the marked benefit of the application of a laser in surgery for paraganglioma, usually an extremely bloody procedure with the potential for damage to the ossicular chain, round and oval windows,

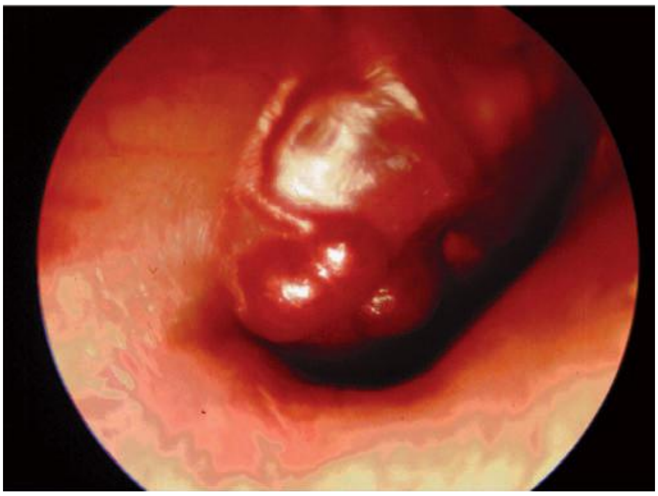

Fig. 6. Glomus tympanicum tumour with bulging of the tympanic membrane. (Courtesy S. Jovanovic)

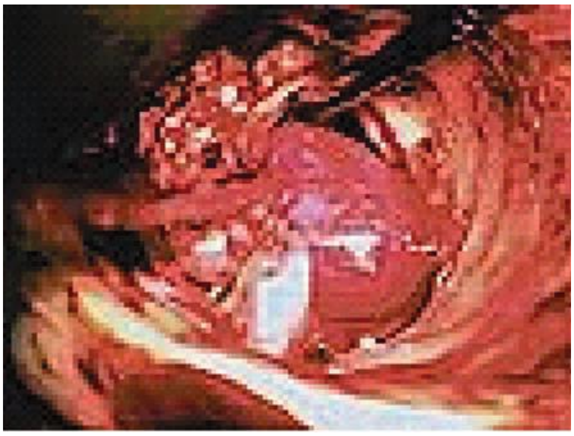

Fig. 7. Glomus tympanicum tumour after elevation of the tympano-meatal flap. (Courtesy S. Jovanovic)

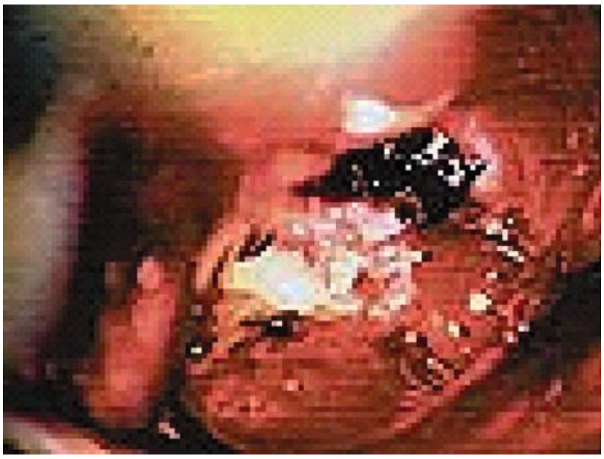

Fig. 8. Shrinkage of the vascular tumour after KTP laser irradiation. (Courtesy S. Jovanovic)

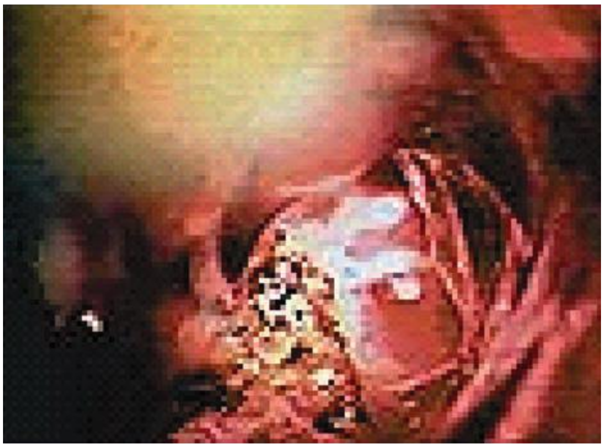

Fig. 9. Cavum tympani after complete removal of the tumour. (Courtesy S. Jovanovic)

and facial nerve. The improved control of bleeding allows better visualisation of the lesion. Demarcation from the normal tissue is thus facilitated, allowing better preservation of the important adjacent anatomical structures, such as the facial nerve, oval and round windows. Complete excision can be achieved in the majority of cases using a transcanal approach, without the need for ossicular dislocation (Parkin, 1990; Robinson *et al.,* 1993).

For more extensive glomus jugulare tumours, arising from the paraganglion in the wall of the jugular bulb and invading the petrous bone and middle ear, the use of the laser is more controversial.

4.6. Laser-assisted, totally implantable electronic hearing aids

The totally implantable electronic hearing aid, TICA (Implex AG, Hearing Technology, Germany), stimulates the inner ear via a piezoelectric transducer coupled directly to the incus. It is necessary to vaporise the neck of the malleus in order to prevent transmission of the vibration to the tympanic membrane and to avoid feedback, since the microphone of the implant is placed underneath the skin of the EAC. The neck of the malleus is easily vaporised with the CO_2 laser (Zenner *et al.*, 2000). Initially, the Er:YAG laser was used for coupling of the transducer rod to the incus body. However, the use of this laser resulted in a temporary threshold shift in some patients. Further evolution of the technique resulted in fixation of the transducer to the long process of incus without the use of a laser.

5. Cholesteatoma surgery

The application of the KTP laser for cholesteatoma has been described in Chapter 34. The laser energy is particularly useful for the removal of cholesteatoma covering a mobile stapes, extending between the crura and the oval window (Thedinger, 1990). In such instances, the laser allows the crura to be ablated at their base without the danger of footplate mobilisation or dislocation, ensuring complete removal of the cholesteatoma in the oval window niche.

For large cholesteatoma of the mastoid, some surgeons use the laser beam in the defocused mode, in order to ‘paint’ different areas of the mastoid cavity and to ablate any potential residual foci of the cholesteatoma (Nissen, 1995). Using the CO_2 laser with scanner systems, cholesteatoma can be ablated very precisely with safe laser parameters (Jovanovic *et al*., 1998).

6. Laser applications in the inner ear

6.1. Cochleostomy

Cochleostomy can be performed using a laser for insertion of the electrodes of a cochlear implant, especially in the case of an ossified cochlea. Experimental studies have been performed (Kautzky *et al*., 1994, 1996) using a Ho:YAG laser to reopen the basal turn of artificially obliterated human cochlea in freshly dissected cadavers. This allowed the intracochlear insertion of the stimulation electrode of a cochlear implant. Computed tomography and light microscopic studies did not reveal any damage to the surrounding structures of laser-recanalised cochleas.

Jovanovic reported an elegant technique for cochleostomy using a CO_2 laser with microprocessor-controlled scanners for insertion of the electrode of a cochlear implant. The laser parameters are the same as those used for the footplate perforation in stapedotomy discussed in Chapter 17 (Jovanovic, personal report).

6.2. Laser labyrinthectomy

Conventional labyrinthectomy has been proposed for the treatment of intractable and long-standing vertigo, but the indications are limited since the hearing cannot be spared. Experimental work on guinea pig maculae of the otolithic organs showed degeneration after irradiation with an argon laser beam through a stapedectomized oval window (Okuno *et al.*, 1990). Since the membranous labyrinth remains intact, preservation of hearing may be possible. Such a surgical procedure has been reported in a 62-year-old woman who developed benign paroxysmal positional vertigo after closure of a perilymph fistula. A laser beam was applied to the macula utriculi, and the oval window was sealed with perichondrium. A Teflon piston was positioned, as in conventional stapedectomy. Two years after surgery, the patient's vertigo had completely disappeared, with preservation of hearing. The macula sacculi cannot be irradiated because the saccular wall contains pigment, and thus may be perforated if irradiated by the argon laser (Nomura *et al.*, 1995).

During conventional singular neurectomy, it is not always easy to identify the nerve in the round window niche. Several laser applications to an area near the singular nerve may result in intense local heat to the nerve (Nomura *et al.,* 1995).

Partitioning of the semicircular canal has also been proposed for the treatment of chronic paroxysmal positional vertigo (Anthony, 1993). Using argon laser irradiation in guinea pigs, Nomura *et al.* (1995) showed marked shrinkage of the semicircular canal, followed by occlusion by fibrosis and ossification. Kartush and Sargent (1995) have treated four patients: using a transmastoid approach, the osseous posterior semicircular canal is fenestrated with a diamond burr. Then a CO_2 laser (0.5 W, 0.1-second pulse, and 600-µm spot size) is applied directly to the membranous labyrinth in order to shrink the membranous canal prior to plugging the bony canal with fascia and bone chips. All these patients have been followed for at least one year, with complete resolution of vertigo and no damage to hearing.

7. Summary

Safety is of paramount importance in the application of any new surgical tool. A basic knowledge of laser physics and the judicious choice of the parameters used with each type of laser are prerequisites for laser use in ear surgery. The main concern still remains potential injury to the inner ear and facial nerve.

There are certain definitive measures that can be put into practice in order to minimise thermal spread while working in the vicinity of the stapes and the facial nerve. The power setting should be low and the exposure time short. Continuous exposure should be avoided, and tissue ablation carried out with single shots. The time interval between the application of shots should be increased so that the tissues have time to cool down. The footplate and fallopian canals should be protected with wet gelfoam. Most importantly, the operator must be aware that the effect that can be seen from the laser strike is only half the story, the spread of damaging thermal energy occurs beyond the site of impact. This is especially true in the case of ossicles, which do not absorb laser energy efficiently and therefore transmit it to the surrounding structures. The Er:YAG laser is a good bone cutter, but its use results in mechanical vibration. It is therefore unsuitable for stapes surgery. Likewise, the Nd:YAG laser should never be used in the vicinity of stapes because of its high scatter.

A number of surgical manoeuvres in the confined space of the ear can be undertaken with the laser. The strikingly bloodless operating field is an obvious advantage allowing an unobstructed view of the various structures. The removal of diseased tissue can be accomplished with relative safety. The incidence of revision surgery in chronic ear disease (*e.g.*, cholesteatoma) seems to be decreasing since the laser has come into use (Chapter 34).

The most beneficial aspect of laser application in the ear is the lack of the mechanical movement associated with conventional instrumentation. This is especially true in cases of revision stapes surgery, in which the postoperative hearing results could be significantly improved (Lesinski and Stein, 1992; Lesinski and Newrock, 1993; Haberkamp *et al.*, 1996; Jovanovic and Schönfeld, 1994; Jovanovic *et al.*, 1997a,b).

In the past decade, since the first edition of this book was published in 2002, there have not been many reports in the literature in laser applications in otology. Conventional surgical techniques with cold instrumentation seem to prevail for their dependability and cost implications. Non-touch CO_2

laser technique for stapes surgery is elegant, but otosclerosis is not common and thus any individual otologist is not going to have a case load which would justify a large capital outlay. Cholesteatoma surgery with the laser seems to reduce the recurrence rate (Chapter 34), but again, requires a fibre transmissible laser such as KTP. The wavelength-specific KTP fibre is marketed for single use and adds considerably to the overall costs.

Laser technology is a useful *additional* tool for experienced surgeons to improve the results of conventional techniques. However, the use of lasers for middle-ear surgery is a departure from established conventional methods. In case of complications, potential litigation with high levels of compensation may ensue. Until more surgeons use this technology and publish their results, lasers in otology remain the preserve of the enthusiasts.

Cost-benefit analysis must also be taken into account, since lasers necessitate a high capital outlay with added revenue implications for fibre delivery. The benefits to the patient of this new technology may outweigh the higher costs. But then, the (possibly better) surgical outcome will hardly be perceived by the patient and translated into higher operation fees for laser-assisted surgery.

Health insurance providers may also decline to re-schedule the laser operative procedure involving extra costs. In this era of universal cost-cutting-exercise, it is the insurance providers who may unwittingly map the path to the hi-tech health care of the twenty-first century!

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MCQ – 33. An overview of lasers in otology

1. The use of laser in otology has been slow to evolve because
    a. Most of the pathology is enclosed in a rigid bony temporal bone which needs initial ablation for access
    b. Most lasers are poorly absorbed by bony tissues which contain very little water
    c. Cold instrumentation is quick and does not have a thermal component which could damage the vital tissues beyond the site of operation
    d. Vaporisation of granulation tissue in the vicinity of facial nerve is problematic since the heat may be inadvertently conducted to it
    e. All of the above

2. Laser usage in otology offers
    a. Cost effective technology due to avoidance for repeat procedures
    b. A technology which can be used by surgeons at all levels of experience
    c. Avoidance of mechanical trauma to the ossicular chain
    d. A bloodless field for an unobstructed view of the pathology
    e. A relatively safe mode of surgical tool for removal of disease in the vicinity of vital structures such as the facial nerve

3. Acquisition of laser technology for otological procedures has not evolved because
    a. It requires of high capital outlay
    b. KTP laser fibre is marketed for single use which adds significantly to the revenue implications
    c. Neither the patient nor the administrators are able to appreciate the benefit since the usage cannot translate in to low morbidity and short inpatient stay
    d. Any benefits such as the preservation of ossicular chain and better hearing results are perceived benefits which cannot translate in to additional fees for the hi-tech expensive modality
    e. All of the above

4. When excising a stenosis in the external canal with the laser,
    a. The direction of excision should be antero-inferior so that inadvertent damage to the ossicular chain is avoided
    b. The direction of excision should be postero-superior since this area is most superficial and easily identifiable
    c. A fine channel is created in the centre of stenosis to assess the position of the tympanic membrane
    d. Vaporisation is best undertaken on a broad front so that the fibrotic tissue is ablated layer by layer to avoid pin-holing the tympanic membrane
    e. Grafting of the raw area is necessary in order to avoid restenosis

5. Laser can be used in the management of the pathology of the tympanic membrane
    a. For the closure of small central defects in the tympanic membrane
    b. For excision of a retraction pocket
    c. For excision of a small atrophic segment of the tympanic membrane to encourage proliferation of epithelium
    d. For vaporisation of the fibrotic tissue covering the tympanic membrane
    e. For creating a tympanostoma in cases of secretory otitis media

6. A non-touch technique of laser application offers considerable advantage over cold instrumentation in the following situations
    a. Rigidity of the ossicular chain due to fibrotic bands which can be vaporised without mechanical movement of the chain
    b. Decompress the facial nerve, thereby avoiding mechanical trauma associated with cold instrumentation
    c. Removal of granulations in the vicinity of vital structures such as labyrinthine fistula
    d. For vaporising adhesions in the vicinity of prosthesis following stapes surgery
    e. For creating a tympanostomy to assess the state of the ossicular chain and the middle ear

7. Lasers can be used in the management of a rigid ossicular chain
    a. For vaporising fibrotic bands
    b. For vaporising fused head of malleus to the surrounding bone
    c. For vaporising bony sclerosis around the head of the malleus
    d. For vaporising tympanosclerotic patches around the chain
    e. For stapedectomy when the sclerotic process involves the oval window

Chapter 34

Functional orthogonal cholesteatoma surgery

J. Hamilton

1. Introduction

The challenge of cholesteatoma surgery is to remove the cholesteatoma permanently and retain or reconstruct the normal functions of the structures housed within the temporal bone. These aims are conflicting. In order that the quality of surgery be measured, it is useful to restate the general objectives of cholesteatoma surgery as four dichotomous and auditable aims.

The problem of residual cholesteatoma is not necessarily an indication of failure of individual effort. The properties of conventional instruments are sometimes the factor limiting the excellence of cholesteatoma surgery. By contrast, the properties of a fibre-guided laser congruently match the problems which beset the complete removal of cholesteatoma. Use of the laser is no substitute for well-honed conventional otological skills, which are necessary to protect the integrity of the facial nerve. The laser reduces the rate of residual cholesteatoma in intact canal wall surgery by a whole order of magnitude. It can be used to remove cholesteatoma from the intact ossicular chain without causing cochlear injury.

A new 'orthogonal' approach is required to remove cholesteatoma from the medial surface of the intact ossicular chain. A combined lateral and orthogonal approach turns out to be the minimum necessary to systematically preserve the ossicular chain during cholesteatoma surgery. The ancillary use of an otological mirror improves cholesteatoma removal from the sinus tympani and anterior epitympanum.

Preservation of the intact ossicular chain not only provides better conductive hearing on average than dismantling and reconstruction, it is also more consistent as it removes the risk of failure of reconstruction. Even a small average improvement in middle ear function results in a large increase in the rate of patient satisfaction, so ossicular chain *preservation* results in significantly higher rates of patient satisfaction than ossicular *reconstruction*.

Surgery for cholesteatoma which preserves the ear canal wall and the intact ossicular chain results from new instrumentation, which has given rise to new concepts, new techniques, new orthogonal approach and new terminology. As a consequence of this innovation, it justifies a name to distinguish it from previous operations. It is termed Functional Orthogonal Cholesteatoma Surgery (FOCS).

Based on the specific auditable outcomes of cholesteatoma surgery, FOCS is more effective than conventional operations for cholesteatoma surgery.

2. Why laser

Evidence presented in the past decade has defined an important role for the fibre-guided laser in cholesteatoma surgery. The laser has been shown to provide a formidable impact on the main aim of cholesteatoma surgery: reducing the rate of residual cholesteatoma. It has also been shown to bestow a powerful effect on preserving useful hearing in the operated ear. No other technology has been shown to improve the main outcomes of cholesteatoma surgery.

In order to understand why the laser is uniquely suited to cholesteatoma surgery, and how it is best applied, it is important to understand the context

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within which it is used. This chapter therefore begins with a description of the nature of cholesteatoma, its effects on the patient and the problems these effects present to conventional surgery. The main body of the chapter relates the author's personal experience of a novel approach to these problems and presents evidence to quantify the benefits and risks associated with the use of lasers in cholesteatoma surgery.

3. The nature of cholesteatoma

Cholesteatoma is an invasive, destructive and progressive disorder of the temporal bone. On the histological scale, it comprises a surface of keratinising squamous epithelium, often associated with inflammatory tissue. On a more macroscopic scale, the epithelial membrane forms an almost closed sheet enveloping a lumen filled with keratin debris. This matrix in this location results in local bone reaction, causing both bone resorption and osteoneogenesis (Friedman, 1956) It gradually expands through the temporal bone by enveloping, adhering to, and eroding those structures it encounters. The only way to actively treat an abnormal physical structure such as cholesteatoma is to remove it.

4. The nature of the temporal bone

The temporal bone forms the major part of the lateral skull base. Most of the interior of the temporal bone is occupied by the adnexal structures of the cochlea: the middle ear space which includes the mastoid air cell complex; the tympanic membrane and ossicles and the external ear canal. Other important structures within its walls are the labyrinth and its sensory nerves, the facial nerve, the major blood vessels to and from the brain and the lowest four cranial nerves.

The anatomy of the temporal bone is manifestly highly complicated and this may influence surgical strategy. On the one hand, the preservation of each of the anatomical structures is desirable since the functional impact of removal of any of these is significant and may be catastrophic. On the other hand, each retained structure acts as a barrier behind which cholesteatoma may shield, thereby hampering its complete removal.

5. General objectives of cholesteatoma surgery

The challenge of cholesteatoma surgery is to remove the cholesteatoma permanently whilst retaining or reconstructing the normal functions of the structures housed within the temporal bone. This general objective of cholesteatoma surgery has two parts: It is directed both against the underlying pathology, and towards maintaining the normal structures and functions of the temporal bone. These aims are conflicting and make cholesteatoma surgery extremely challenging.

6. Specific aims of cholesteatoma surgery

In order that the quality of surgery be measured, it is useful to restate the general objectives of cholesteatoma surgery as four specific auditable aims:

- There should be no residual cholesteatoma within the middle ear after surgery is completed;
- There should be no growth of new cholesteatoma after surgery;
- The ear should be robustly dry after surgery;
- The ear should provide socially useful hearing after surgery.

These aims are auditable as follows: Residual cholesteatoma is determined by a second-look procedure, a delayed postoperative digitally weighted magnetic resonance (DW-MR) scan or prolonged follow up (five years). Growth of new cholesteatoma occurs as retraction of the reconstructed tympanic membrane and is time-dependent and requires long-term (five years) follow up of the patient after surgery. To be robustly dry means that the ear should be able to tolerate exposure to water without resulting infection. The hearing function of the operated ear should satisfy the Belfast Rules of Thumb.

The Belfast Rules of Thumb are calculated using two audiometrical criteria, which have been found to correlate well with the patient's satisfaction with hearing in the operated ear. The two criteria are:

- Air conduction threshold of 30dB HL or less in the operated ear;
- Air conduction threshold within 15 dB of the non-operated ear.

The ear is deemed to satisfy the Belfast Rules of Thumb if the air conduction threshold in the operated ear satisfies at least one of these criteria.

The first two aims reflect the intention to completely and permanently remove cholesteatoma from the middle ear. This requires not just that the middle ear be cleared of cholesteatoma, but also that no subsequent new growth of cholesteatoma occurs.

The second pair of aims reflects the intention to restore the normal functions of the temporal bone. A comprehensive list of all of the functions of the structures within the temporal bone could be tabulated. Fortunately, most of these are rarely affected by cholesteatoma. When establishing a list of auditable functional outcomes, it is practical and efficient to keep to the main symptoms which affect the patient. These are ear discharge and hearing loss, which affect 98% of ears with cholesteatoma.

Note that each of these four outcomes is a simple dichotomous (yes or no) measure.

7. Summary of contextual options in cholesteatoma surgery

The intention to extract, with minimum morbidity, a disease with pervasive and destructive properties from the complex anatomy of the temporal bone cannot be undertaken without consideration that this process necessarily consists of conflicting pathological and functional aims. Any improvement in the treatment of cholesteatoma needs to recognise and resolve this conflict. The true worth of any proposed treatment can be measured using the specific aims tabulated in paragraph 6.

8. The problem of residual disease in cholesteatoma surgery

No surgeon, no matter how skilled, how experienced or how assiduous, has been able to remove all cholesteatoma in all operations in one attempt. In fact, the majority of surgeons do not get anywhere close to removing all disease in all cases. Renowned and dedicated surgeons who have audited and published their work generally record residual cholesteatoma rates of 15-30% (Sheehy, 1977; Sanna, 1984; Haginimoro, 2008).

It is evident that the problem of residual disease is not an indication of failure of individual effort. The corollary is to question why no amount of ‘trying harder’ is likely to improve the clearance of cholesteatoma. The author’s thesis is that the conventional instruments are not sufficiently suited to the task, thus limiting complete clearance of cholesteatoma.

9. Risk factors for residual cholesteatoma

Five factors have been identified statistically using multivariate analysis to be features which increase the likelihood that cholesteatoma will be incompletely cleared from the temporal bone at the completion of surgery (Gristwood, 1990; Rosenfeld, 1992; Roger, 1996; Iino, 2000). These risk factors are:

- The presence of barriers to visual inspection of cholesteatoma;
- The association of cholesteatoma with bleeding;
- Adherence of the cholesteatoma to the temporal bone tissues;
- Concerns about moving the ossicular chain;
- Inexperience of the surgeon.

It hardly needs to be mentioned that cholesteatoma is more difficult to remove when it cannot be seen directly. Unfortunately the anatomy of the temporal bone means that recesses into which the surgeon cannot directly peer exist. When cholesteatoma occupies these sites it may be difficult to remove it, especially when more of these risk factors are also present.

The association of cholesteatoma with bleeding reduces the surgeon’s ability to see the cholesteatoma during dissection. This particular problem is worsened if the cholesteatoma is also hidden from direct view.

Adherence of the cholesteatoma to the temporal bone tissues means that it does not dissect free easily. This is a particular problem if the cholesteatoma is also friable. If the cholesteatoma is hidden from sight, the surgeon may not notice that cholesteatoma has been left.

Concerns about moving the ossicular chain may hinder the surgeon for fear of transmitting destructive amounts of energy into the cochlea because of movement caused by the surgical instruments.

The solution to the problem of residual cholesteatoma is a surgical instrument which has characteristics that remedy as many of the above problems as possible.

10. Technological solutions to the problem of complete cholesteatoma removal

Otological mirrors and endoscopes have solved the problem of inspection of cholesteatoma hidden behind the ossicles and intact ear canal or any other temporal bone obstruction. However, they do not solve any of the other problems of cholesteatoma surgery, as these relate directly to the act of dissection. The fibre-guided laser is the only device with the appropriate properties:

- Pathological tissue is removed *without movement* of the target;
- The laser is easier to use than conventional instruments;
- The laser energy can be directed around corners;
- Otological surgery with an appropriate laser can be bloodless.

11. The properties of the fibre-guided laser

Lasers generate intense electromagnetic radiation. In surgical applications, this radiation is guided from the laser and applied to the tissue. The absorption of laser energy by the tissue results in its conversion to heat which ablates tissue. In this way the pathological tissue can be vaporised, a process which requires no movement of the affected structure. Laser offers a number of advantages.

In the middle of the operative field lies the ossicular chain, linked to the cochlea. The latter is readily damaged by the movement that is an integral part of the elevation of disease by conventional instruments. The key advantage of treatment by surgical lasers of cholesteatoma is that the pathological tissue is removed without movement of the target. No other instrument can offer this property.

Surgical laser energy is directed at the tissue to be ablated and the laser shutter is opened, usually by means of a pedal. This 'point and shoot' property of laser surgery requires much less dexterity than the manipulation of conventional otological dissection instruments.

An essential requirement for an instrument used in the complex three-dimensional temporal bone is that it should be able to be operated around obstacles which prevent direct view. From the perspective of cholesteatoma surgery, the most useful lasers are those whose radiation can be guided around corners within a fibre. Moreover, visible laser light can be bounced off appropriate mirrors. This means that hidden cholesteatoma can be indirectly viewed and removed with the combination of a laser and a mirror.

Cholesteatoma is associated with chronic inflammation and is therefore frequently associated with granulation tissue. Operating with conventional instruments causes bleeding which hinders the identification of cholesteatoma. By contrast, laser dissection can be haemostatic as the wavelength of the laser can be selected to match one of the absorption peaks of haemoglobin in the visible light range.

The properties of a fibre-guided laser congruently mirror the problems which beset the complete removal of cholesteatoma. It is therefore reasonable to regard the fibre-guided laser as a rational solution to the problems which hinder the removal of cholesteatoma.

12. Commercially available fibre-guided lasers

A variety of fibre-guided lasers are commercially available. Lasers for use with fibres have been, until recently, constructed to generate electromagnetic energy within the visible light spectrum. Laser radiation that has a wavelength in the visible light spectrum will have the familiar properties of visible light; the most important of these is the phenomenon of total internal reflection within glass, as this means that the laser radiation can be transmitted along an optical glass fibre. The first surgical laser to exploit the optical fibres for the transmission of light energy was the Argon laser forty years ago, emitting at 490 nm wavelength light. A second visible light laser, Potassium Titanyl Phosphate (KTP) crystal was introduced for ear surgery in 1980 by halving the wavelength of radiation from a Neodynium-Yttrium Aluminium Garnet (Nd:YAG) laser. The later introduction of rare earth metal diodes has now led to the development of many visible light wavelength lasers.

Glass is not sufficiently anhydrous for optical fibres to be used with infra-red wavelength lasers. The delivery of CO_2 laser energy by a fibre was delayed until a hollow waveguide with an appropriately reflective inner surface was developed (Devaiah, 2005). At the time of writing, the expense of these fibres continues to disadvantage the CO_2 laser in otology.

Otological laser fibres need to be very fine so that they can be used around the ossicular chain. A 200 μm fibre is much easier to use than a 300-400μm fibre. The author prefers to use a visible light KTP laser, delivered via 200 μm fibre. At 532 nm emission, it is strongly absorbed by haemoglobin, and thus, is haemostatic.

Standard vaporisation of diseased tissue can be achieved using a 200 μm fibre with the power set at 1 W. Delicate work on the stapes requires less rapid delivery of energy. This is achieved by reducing the power of the laser, to 0.5 W and by shortening the duration of the radiation pulse, to 0.1 s. Note that laser radiation emanating from a fibre is not collimated but diverges as it emerges at the tip of the fibre. A lower rate of energy delivery can therefore also be achieved by holding the fibre tip further away from the target. However, the fibre is usually held with the tip almost in contact with the target to achieve a precise effect.

13. Safety and the fibre-guided laser: general principles

Before using a laser as a surgical instrument, the surgeon needs to be aware of the harm the laser can cause if used without care or expertise. The KTP laser has the potential to interact with any tissue which contains blood vessels. It has the potential to interact with, and therefore vaporise, any structure within the temporal bone. The use of a laser in cholesteatoma surgery is no substitute for adequate knowledge of temporal bone anatomy and surgical dissection skills. Without these, a surgeon with a laser is a danger to the patient.

13.1. Guidelines for safe use of the laser near the facial nerve

Laser energy should not be directed at the facial nerve. Whatever the physical characteristics of the fibre guided laser, the facial nerve is at risk of injury if it absorbs laser energy. The guidelines that should be strictly observed for the preservation of facial nerve integrity when using a laser during cholesteatoma surgery are:

- The surgeon must have the skill to define the course of the facial nerve in the temporal bone before planning to undertake cholesteatoma surgery with a laser;
- The surgeon should define the course of the facial nerve in every case of cholesteatoma before the laser is switched on;
- The laser should not be used to remove cholesteatoma until the relationship of the target to the facial nerve has been established;
- The laser should not be used to remove cholesteatoma from the facial nerve or from bone covering the facial nerve. The surgeon should not attempt to substitute the use of a facial nerve monitor in place of these guidelines.

13.2. Guidelines for safe use of the laser near the open labyrinth

The open labyrinth is encountered most commonly in cholesteatoma surgery as a fistula of the lateral semicircular canal. The surgeon should be forewarned about this circumstance by a pre-operative CT. The surgeon should not use the laser to remove cholesteatoma from the fistula. Laser energy should not be directed into the open labyrinth. Visible light is transmitted with minimal attenuation by the clear labyrinthine fluids. Directing visible light laser energy into the open labyrinth will put the delicate membranous structures at risk of injury. Infra-red laser energy is absorbed by water. Directing energy of this wavelength into the perilymph may cause the fluid to heat in an explosive manner. This may cause acoustic trauma or injury through loss of perilymph.

13.3. Guidelines for safe use of the laser on the ossicles

The stapes superstructure is extremely delicate. Fibre-guided lasers are used to remove the stapes superstructure in stapes surgery. Any attempt to remove cholesteatoma from the superstructure of the stapes requires great care.

The long process of the incus is normally a more stout structure than the stapes arch. Sometimes, however, the long process is attenuated by disease, in which case the laser must be used with caution.

On the stapes arch and the attenuated long process, it is preferable to use a technique in which the cholesteatoma is dissected by strikes tangential to the surface of the ossicle.

Elsewhere on the ossicles the cholesteatoma can be vaporised directly from the surface of the bone.

13.4. Guidelines for safe use of the laser near the dura and great vessels

In general, the laser should not be used to ablate tissue from the exposed dura, sigmoid sinus, jugular bulb or internal carotid artery. These caveats notwithstanding, the laser offers an entirely new means of removing cholesteatoma.

14. The impact of the laser on complete clearance of cholesteatoma

The properties of an ideal device for the removal of cholesteatoma exactly match the properties of the fibre guided laser. No instrument is better suited than a laser to removing an adherent disease from an inflamed and intricate three-dimensional space that contains an organ complex, which is damaged by movement. The rational basis for using the fibre-guided laser in cholesteatoma surgery is strong and justifies further investigation by clinical trial.

Accordingly, the author undertook a prospective, two-centre trial to compare two independent groups of patients undergoing primary intact canal wall cholesteatoma surgery at two different hospitals (Hamilton, 2005); a fibre-guided laser was available at only one of the two hospitals. This design surrendered the scientific power of a randomised trial in order to maintain the ethical integrity that each group was receiving the best possible treatment that their hospital could provide. The design of the study was organised carefully to minimise bias:

- Apart from the laser, the equipment and treatment in the two centres was identical;
- The same surgeon undertook all of the surgery;
- The outcome was a simple and unequivocal dichotomous measure, which was witnessed by the theatre staff: either there was residual disease at a second look operation, or there was not;
- Important baseline features were also prospectively recorded;
- Patients were recruited over nearly three years, and all patients undergoing this surgery were included except for those who deliberately did not undergo a second look operation, either because the cholesteatoma sac was removed without rupture at the first operation or because the canal wall was removed to gain access to the disease. As a coda to the main study this small group of patients were followed up for over five years to check for residual disease;
- KTP laser was used in 36 patients who entered into the laser wing of the trial, whilst 33 without a laser were included (Fig. 1). Only one patient, included in the main trial failed to attend for second-look surgery, despite reminders by mail and telephone.

The group who received treatment with the laser consisted of 35 individuals. One patient had residual disease.The group who received treatment without the laser comprised 33 individuals. Ten patients had residual disease. All patients were assessed at second stage surgery:

- Of the 35 laser patients' outcomes recorded, only one had residual cholesteatoma;
- Of 33 patients treated without a laser, ten had residual cholesteatoma;
- Multiple regression analysis confirmed that the only factor significantly associated with the outcome was the use of the laser.

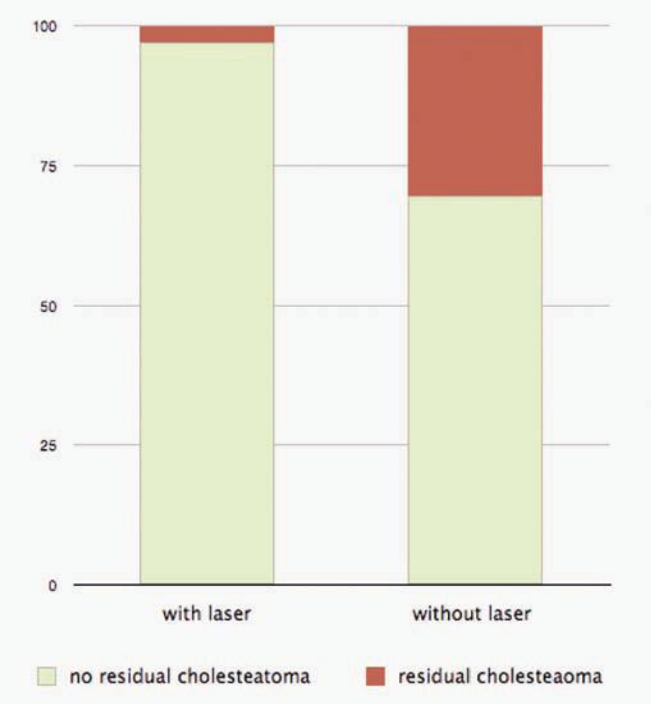

Fig 1. Effect of fibre-guided laser on complete clearance of cholesteatoma.

The treatment effect is truly formidable: the number need to treat (NNT) was 3.7, which indicates a very powerful effect. This study provided empirical evidence to support the theoretical suitability of the fibre-guided KTP laser for cholesteatoma surgery. Moreover, it has provided a measure of the benefit of using this type of laser in cholesteatoma surgery. The treatment effect is huge and use of the laser reduces the rate of residual disease by a whole order of magnitude. Having confirmed this advantage to using the laser, it was then possible to seek secondary benefits from this approach to cholesteatoma surgery:

- It may permit more frequent preservation of the intact ossicular chain;
- It may allow second look procedures to be directed at ossicular reconstruction;
- It may permit more cases of cholesteatoma surgery to be performed as a single-stage operation.

15. Treatment of the ossicles in conventional cholesteatoma surgery

The ossicular chain is disrupted in most cases of cholesteatoma. In all of these cases restoration of hearing, if feasible, will require an ossiculoplasty. Approximately two out of every seven cholesteatoma cases (28%) present with an ossicular chain which remains in continuity. However, even in this circumstance, there are strong arguments for dismantling the chain:

- The ossicles may act as a barrier to complete removal of cholesteatoma. The surgeon may feel that, in order to remove the cholesteatoma completely, the barrier concealing it needs to be removed (Fig. 2).
- Three problems confront the surgeon intending to preserve the ossicular chain in the presence of cholesteatoma:
  1. Removal of cholesteatoma from behind the barrier caused by preservation of the ossicular chain;
  2. Removal of cholesteatoma from the anterior epitympanum in front of the intact malleus head;
  3. Removal of cholesteatoma from the medial side of the ossicular chain, especially from over the facial nerve in the epitympanic gutter.

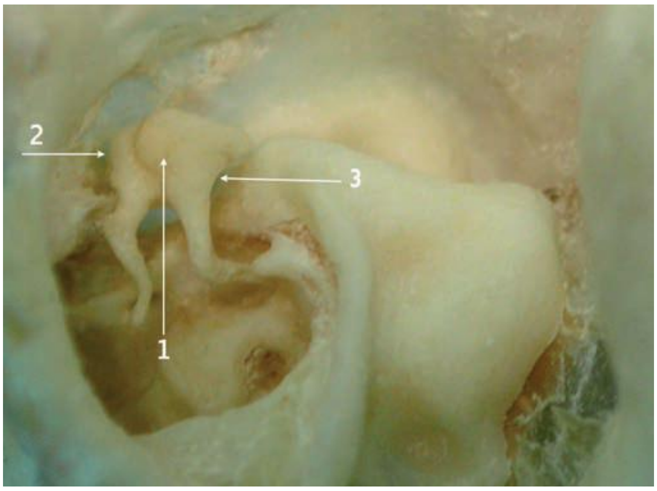

Fig. 2. Problems caused by the preservation of the ossicular chain in the presence of cholesteatoma:
1.Removal of adherent cholesteatoma, particularly from behind the barrier caused by preservation of the ossicular chain without causing cochlear damage;
2.Removal of cholesteatoma from the anterior epitympanum in front of the intact malleus head;
3.Removal of cholesteatoma from the medial side of the ossicular chain, especially from over the facial nerve in the epitympanic gutter.

- When cholesteatoma involves the ossicles, and cannot be easily removed, many surgeons remove the ossicle rather than risk injuring the cochlea by aggressive dissection of the adherent disease, even if the ossicular chain is intact.
- Ruedi (1959) presented evidence implicating epitympanic granulation tissue as a cause of attic cholesteatoma in an animal model. In keeping with this pathology, he advocated that the epitympanum should be cleared during cholesteatoma surgery in order to clear all infected and potentially infected tissue from this area. The procedure necessitates the removal of the head of the malleus and the incus as part of this epitympanectomy. This advice is widely followed.

There is, therefore, a well-established body of opinion which suggests that, to dismantle the ossicular chain and subsequently rebuild it, is a good option in cholesteatoma surgery. However, the observed results of ossicular reconstruction do not present such a positive picture.

A series of long-term hearing results after cholesteatoma surgery was presented in 1999 (Hamilton, 2000). The hearing in each operated ear was categorised dichotomously as good or poor; depending on whether the Belfast Rules of Thumb (Smyth, 1985) were met, as this measure accords well with patient satisfaction after the procedure. The results were also classified on the basis of the procedure undertaken. The proportion of ears with good hearing after ossiculoplasty onto the stapes head, mainly following malleus to stapes assembly during cholesteatoma surgery was 0.535. The proportion of patients with good hearing after ossiculoplasty onto the malleus footplate was 0.495. Clearly, these results left room for improvement.

An obvious solution to this problem was to find methods which would improve the results of ossiculoplasty. A great deal of progress in this regard has been achieved in the last decade. This has been consequent upon advances in middle ear modelling using the finite element method (Koike, 2000), and advances in the observation of middle ear function using laser Doppler vibrometry (Morris, 2004). Excellent work in this field has emphasised the need to minimise tension within the ossicular reconstruction. Stability of the reconstruction, therefore, no longer relies on the tension caused by the elastic recoil of the ossicles, which was formerly deliberately encouraged by placing a prosthesis which was fractionally too long for the interval between the recipient ossicles. Stability in ossicular reconstruction is now achieved by using prostheses which are congruent to the recipient ossicles and which lock onto the ossicles without displacing them.

16. Technique for the systematic preservation of the ossicular chain in cholesteatoma surgery

An alternative and less obvious approach to the problem has been provided by the laser. Since the laser removes disease by vaporisation, without movement, it is reasonable to suppose that this property would allow a laser based surgical technique to overcome concerns about cochlear damage whilst removing cholesteatoma from the ossicles. Starting in 1999, the author gradually developed techniques to remove cholesteatoma from the surface of the ossicles. The problems raised by the ossicles with regard to the removal of cholesteatoma were:

- How to remove firmly adherent cholesteatoma from the surface of the ossicles;
- How to remove cholesteatoma concealed by the ossicles (see Fig. 2).

Cholesteatoma is removed from the body of the incus and the malleus head simply by vaporising the disease. The relatively massive bone of the body of the incus and all parts of the malleus tolerates the energy densities used in cholesteatoma surgery (25 Wmm^{-2}) and does not suffer clinically significant necrosis. The healthy long process of the incus will also tolerate this laser energy density if used in pulses of less than a second.

The finer bone of the stapes superstructure and also of the disease-eroded long process is less robust and is at risk of vaporisation at the energy density levels required to vaporise cholesteatoma. In order to minimise the risk of necrosis of these delicate structures, a dissection-style removal of cholesteatoma, using the laser at a tangent to the surface of the bone, is still preferable on these surfaces. The dissection technique, in which the already elevated cholesteatoma is held taut using a micro-sucker whilst the interface between the still adherent cholesteatoma and the ossicle was divided using the laser, results in a small amount of ossicular movement due to traction on the ossicle by the micro-sucker through the taut sheet of cholesteatoma.

There are two main areas which cause a problem for removal of cholesteatoma from behind the barrier formed by the ossicular chain. These are:

- The anteromedial surface of the malleus head and neck;
- The interval deep to the ossicles and lateral to the facial nerve.

The region from which the removal of cholesteatoma is most hindered by the anatomy, is the space anterior to the malleus head. In an ear with a well pneumatised epitympanum, it may be possible to view this area indirectly using an otological mirror. Using one of the unique properties of the laser, it could be possible to remove disease in this area by bouncing the laser beam off the otological mirror. However, in an ear with a more compact epitympanum, there will not be adequate space to safely insert an otological mirror past the ossicular chain, and so a direct approach by removal of the bone shielding this area is necessary. This can be performed either by undertaking an anterior epitympanotomy or by mobilising the posterior canal wall in this area. This is a labour-intensive technique in either case, not just because of the resection but also because the resulting defect needs to be reconstructed.

The other space from which removal of cholesteatoma is difficult is the interval deep to the ossicles and lateral to the facial nerve. Not only is this area hidden from sight but the presence of the facial nerve appears, at first sight, to rule out the use of the laser in this region.

The solution to working in this area comes from the anatomy of the ossicular chain: the orientation of the chain, as indicated by a vertical plane through the short process of incus and the anterior process of the malleus, lies at approximately 45° to the lateral surface of the skull. This means that a line of sight sufficiently posterior to the ossicles will provide a direct view of the medial surface of the incus and the malleus head. This viewpoint is achieved by carefully dissecting out the pneumatised temporal bone until a pronounced sino-dural angle has been formed. Access to the critical area is improved further by widening the posterior tympanotomy onto the skeletonised facial nerve and up to the blue-lined lateral semicircular canal. When approached and exposed in this way, the space medial to the ossicular chain and lateral to the facial nerve and lateral semicircular canal is directly visible as a deep and steep sided channel, referred to as the 'para-ossicular epitympanic fossa', or 'epitympanic gutter' (Fig. 3). This perspective on the disease medial to the ossicular chain within the epitympanic gutter is termed the 'orthogonal' view.

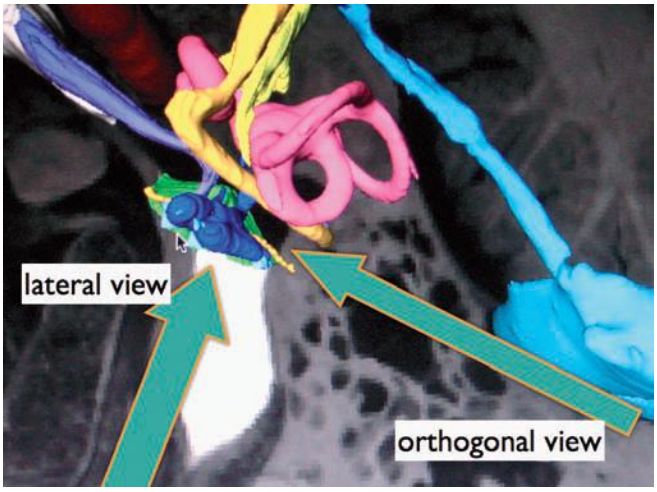

Fig. 3. The orthogonal view.

In order to systematically retain the ossicular chain in cholesteatoma surgery, it is essential to obtain a direct view of the medial surface of the ossicles and the tympanic segment of the facial nerve. A purely lateral approach cannot achieve this. The view obtained by maximally opening the sinodural angle and the posterior tympanotomy can achieve this. The author has termed the latter projection as the 'orthogonal' view.

Surgery limited to a 'lateral' approach alone, such as practiced during atticotomy or permeatal endoscopic surgery, requires the ossicular chain to be dismantled in order to remove cholesteatoma completely deep to the malleus head and incus (Marchioni, 2011). The view through the sino-dural angle and extended posterior tympanotomy, the 'orthogonal' approach, provides extra information which cannot be obtained through the lateral view and which is needed to remove disease safely without removing the ossicular chain.

Having gained access to the epitympanic gutter, the surgeon is faced with the task of removing inflamed and adherent disease from this space. This task is affected safely if the following three rules are borne in mind at all times:

- Use the laser in preference to steel instruments on the ossicles (Fig 4);
- Never use the laser on the facial nerve;
- Always work where you can see what you are doing (i.e., on the nearest disease first).

The space between the medial surface of the ossicular chain and the facial nerve has been termed the epitympanic gutter by the author. The space is best approached through the sinodural angle and posterior tympanotomy (termed the 'orthogonal' approach by the author). The facial nerve can be identified in the pyramidal region and traced forward exclusively using conventional instruments. The medial surface of the ossicles can be directly viewed and disease removed from this side of the fossa exclusively with the laser. The tip of the laser fibre can be placed beyond the facial nerve so that all times the laser is pointed away from the nerve. Conventional instruments are used to remove the cholesteatoma from the facial nerve as necessary.

By working from near to far, the surgeon can minimise the effect of bleeding on the surgical field and can be confident about the anatomical structures he or she is revealing and manipulating as the cholesteatoma is removed. The surgeon will in this way be able to identify the facial nerve as the cholesteatoma is steadily and progressively elevated from this surface. The surgeon can be confident about identifying any dehiscence of the nerve. Similarly, the ossicles will be progressively identified as the cholesteatoma is vaporised from their surface.

By using this technique and the orthogonal view, cholesteatoma can usually be removed from the short process of incus, the medial surface of the incus, the long process of the incus, the posteromedial surface of the malleus head, the capitulum, the processus cochleariformis and the facial nerve. The superior part of the epitympanum also can be cleared comparatively easily.

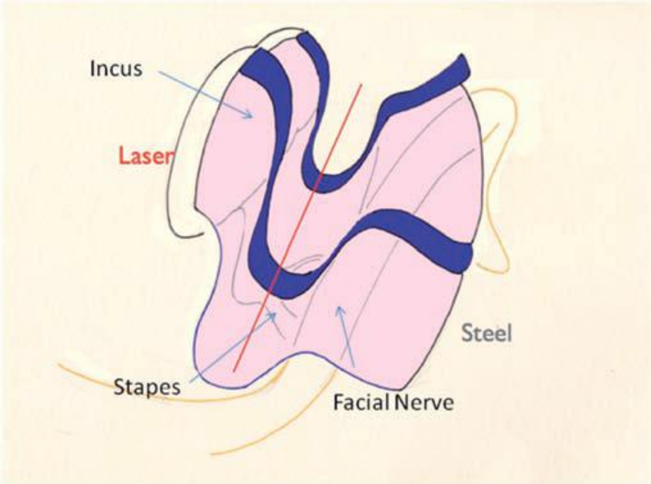

Fig. 4. The paraossicular epitympanic fossa (epitympanic gutter). The ossicular chain, facial nerve and cholesteatoma sac as viewed from the orthogonal approach.

17. Use of the otological mirror during cholesteatoma surgery

It is characteristically difficult to obtain a direct view of the sinus tympani and that part of the epitympanum which is anteromedial to the malleus head and neck. These regions can be inspected with an endoscope, but directing a laser beam off a mirror is the most effective means of removing cholesteatoma from these regions. This technique requires great concentration and no impediment to the surgeon's view. The surgeon must ensure that the mirror is in perfect condition and that the surgical view is not hampered by bleeding or laser smoke:

- It must be ensured that the mirror has no scratches on its surface. The effect on the surgeon's perception of the reflected surgical field is diminished out of all proportion to the minor physical damage sustained when the mirror is first scratched.
- Without good haemostasis there is insufficient time to carefully insert the otological mirror and line up the target, mirror, laser and surgeon's view. If the mirror is moistened by blood, it must be removed from the ear and cleaned, or else the laser light will be absorbed by the blood on the surface of the mirror. The target will not be affected and the blood will be carbonised on the mirror. Hypotensive anaesthesia is valuable and, in addition, topical adrenaline may be required to obtain a sufficiently dry field for this technique.
- To insert a laser fibre, a mirror and an otological micro-sucker clearly requires more hands than the surgeon can offer. Although it is possible to use a combined fibre-guide and suction device, these are usually too bulky for the demanding work in the epitympanum. It is preferable and perfectly adequate for an assistant to hold a large otological sucker no deeper than the entrance to the mastoid cavity and out of the surgeon's line of sight.
- Great care is then required to insert and remove the mirror without knocking the ossicular chain. Once inserted, the mirror and laser are held so that the laser beam is aligned with the surgeons view. Even if there were no guide beam, the surgeon will then be able to see in the mirror the area which the reflected laser beam will affect. In fact, the reflection of the laser guide beam on the target area will be readily visible in the mirror.

18. Auditory assessment of the systematic preservation of the ossicular chain

The fibre-guided laser promises an entirely new way to maintain hearing in cholesteatoma surgery: by removing cholesteatoma from the intact ossicular chain, instead of dismantling the chain and subsequently reconstructing it. In order to test whether this new style of surgery was a benefit to patients a second trial was conducted (Hamilton, 2010).

Two trial groups were compared: in both groups only patients undergoing canal wall up surgery were included.

- In the first group, cholesteatoma was removed from the intact chain and the chain was preserved at the end of surgery;
- In the second group, the chain was dismantled and reconstructed by an ossiculoplasty on to the capitulum of the intact stapes. Both malleus to capitulum assembly and tympanic membrane to capitulum assemblies were included in the latter group.

Ears in which the chain was dismantled and the tympanic membrane draped over the capitulum were not included.

Since the intact chain acts as an extra barrier to removal of disease, the trial also investigated whether the new procedure increased any risks of surgery: the rate of residual disease, injury to the facial nerve and injury to the cochlea were all measured in both groups.

The trial also compared the hearing outcomes in the two groups. This was performed using two outcome measures derived from the postoperative audiological assessment: the conductive hearing loss, which is a useful assessment of the function of the middle ear reconstruction; and the Belfast Rules of Thumb, which is strongly correlated and therefore a useful approximation to the patient's subjective evaluation of the benefit of the intervention. The audiological assessments were undertaken one year after surgery. Consecutive patients were included from 1999 to 2007. The same surgeon supervised or undertook all of the surgery. None of the risks of surgery were increased by the new approach to ossicular preservation. The conductive hearing loss differed between the two groups in two ways:

- The median conductive hearing loss for the intact chain was 4 dB less than the reconstructed group;
- The reconstructed group contained two subgroups with different distributions. The better subgroup

> had a similar distribution to the intact chain group and probably represents the spread of results obtained when the middle ear is adequately reconstructed. The worse subgroup was markedly different. It is probable that this latter subgroup represents ossiculoplasties which are technical failures and which have not adequately restored the structure of the middle ear.

This means that preservation of the intact ossicular chain not only provides better conductive hearing than reconstruction in general; it also removes the risk of failure of reconstruction.

Analysis using the patient-related outcome identified a further benefit of ossicular preservation: the rate of patients experiencing benefit is critically sensitive to the improvement in middle ear function. Hitherto, there has been limited understanding of the sensitive dependence of patient benefit on small changes in middle ear function. Even a small average improvement in middle ear function results in a large increase in the rate of patient satisfaction (Fig. 5). This is reflected in the odds ratio for success with intact surgery compared with ossicular reconstruction. In this trial the odds ratio was 2.73, which indicates a powerful effect.

The parameters which most influence patient benefit were revealed by multivariate analysis to be the baseline cochlear function and the type of middle ear reconstruction. In other words, the stringent requirements of patient satisfaction are further limited by the preoperative cochlear function. This finding stresses that the surgical technique should not cause extra cochlear damage. ‘No movement’ vaporisation of cholesteatoma facilitates this.

Patients undergoing surgery with the laser had preservation of the ossicular chain and this group had an 87.5% useful hearing rate. The other group underwent dismantling of the chain and subsequent reconstruction onto the stapes superstructure. The success rate in this group was 66.6%.

This trial suggests that systematic use of the fibre-guided laser in cholesteatoma surgery enables the surgeon to perform new procedures which provide outcomes that cannot be matched by conventional techniques. The patient’s experience is powerfully enhanced by an operation that not only provides critically better hearing, but also a more consistent result than conventional surgery.

19. Conclusions

The two studies detailed in this chapter indicate that the introduction of the fibre-guided laser is an important advance in cholesteatoma surgery. They provide plausible evidence that the fibre-guided laser not only enables the surgeon to achieve better results in pursuit of the primary aim of cholesteatoma surgery: total removal of cholesteatoma. It also addresses patients’ main concern, obtaining improved hearing.

The original proposition upon which this work is based was that *conventional instruments are a factor limiting the results of cholesteatoma surgery.* This premise was based on the author’s belief that the properties of these instruments were incompatible with the challenges of balancing the functional and pathological needs of excellent cholesteatoma surgery. The properties of the fibre-guided laser, by contrast, suit these requirements very well.

The large improvement in the complete clearance of cholesteatoma obtained by using the laser substantiated this thesis. In this early work the laser was merely an ancillary tool, the properties of which, it had become clear, could be put to more complete use around the ossicular chain. In the past, the surgeon removed structures which impeded the difficult process of removing cholesteatoma and then

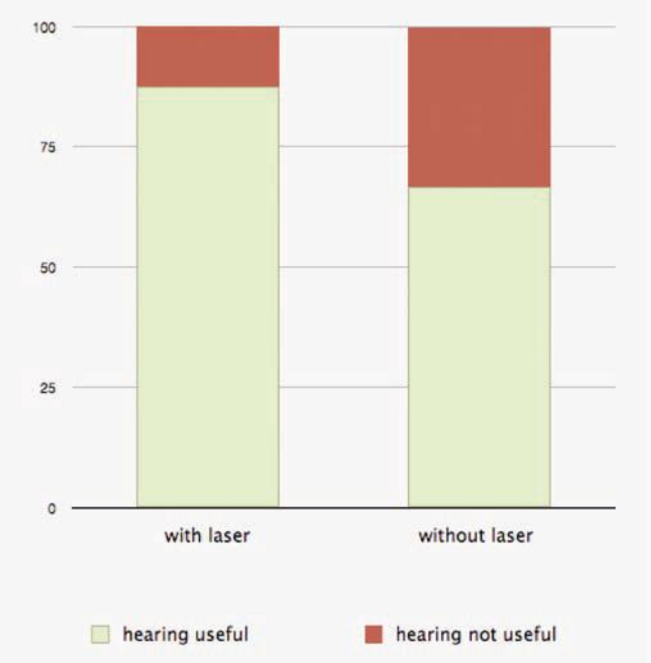

Fig. 5. Assessment of hearing after cholesteatoma surgery using a patient-related outcome measure.

considered reconstructing these at a later stage. With the laser it is now possible for highly conservative surgery to be performed. All the normal structures of the ear can be preserved, as the laser removes the cholesteatoma from their surfaces as part of this new functional cholesteatoma surgery: *the Orthogonal approach.*

To systematically preserve the ossicular chain during cholesteatoma surgery, it is necessary to have an extra approach which circumvents the rampart presented by the ossicles and provides access to the medial surface of the ossicles and the epitympanic gutter. Because this second viewpoint provides information which cannot be gained from the lateral approach, the author has termed it the 'orthogonal' approach. The term 'orthogonal' is appropriated from mathematics where it is used to describe an independent and mutually exclusive point of reference. In geometry it describes a set of perpendicular axes. A combined lateral and orthogonal approach turns out to be the *minimum* necessary. The two-dimensional 'atticotomy' or 'front to back', purely lateral approach, which has been a reasonable technique when the ossicular chain has been dismantled, is inadequate for this type of *functional* surgery.

The laser-assisted combined lateral and orthogonal approach with preservation of the ossicular chain simultaneously enables both the more effective removal of cholesteatoma and the more effective preservation of the function of the ear, thereby achieving the fulfilment of the original inspiration. This Functional Orthogonal Cholesteatoma Surgery (FOCS) is a stepwise improvement in the treatment of cholesteatoma resulting from new concepts, new instrumentation, new techniques, new orthogonal approach and new terminology.

20. The future

At present the second stage operation remains the gold standard assessment of the presence of residual cholesteatoma. The development of non-echo-planar imaging (non-EPI)-based diffusion-weighted (DW) magnetic resonance imaging (MRI) has introduced a technology which may make the systematic second stage operation obsolete (De Foer, 2008). If the potential of the radiological investigation is confirmed, the need to maximise the likelihood of disease removal means that the preferred treatment pathway will become a laser assisted single procedure with an interval MR scan to seek residual disease. It is difficult to imagine how the drive to achieve single stage intact canal surgery could possibly succeed if the use of a laser were not part of the surgical strategy.

21. Envoi

The properties of the laser have generated a new type of surgery for cholesteatoma, known as *FOCS*. The important structures of the ear are retained whilst the disease is cleared more effectively. This procedure restores an ear with normal resilience to infection. The odds ratio for preserving or restoring useful hearing is three times higher than the best conventional surgery. The rate of residual disease is an order of magnitude lower than conventional canal wall up surgery.

The introduction of the laser as a key component in cholesteatoma surgery already has improved outcomes so much that a senior commentator has questioned whether it is reasonable to offer treatment without the use of a laser (Browning, 2005).

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MCQ – 34. Functional orthogonal cholesteatoma surgery

1. Complete clearance of cholesteatoma, with virtually no recurrence cannot be achieved with conventional cold instrument surgery because
    a. The intact or partially eroded ossicular chain provides a barrier to cholesteatoma deep to it
    b. The cold instruments are bulky and cumbersome
    c. The surgeons lack the adequate surgical skill
    d. The cholesteatoma sac is adherent to the ossicles and does not allow its removal without causing ossicular movement or dislocation
    e. In some cases inflammatory changes result in oedema of the mucosa and cause intraoperative bleeding which obstructs the view of the anatomy

2. In conventional cold instrument cholesteatoma surgery, it is usual
    a. That the reconstruction of the ossicular chain is routinely undertaken at the end of surgery
    b. That it is staged to ensure that there is no recurrence
    c. That the improvement in hearing may not be achieved even if the reconstruction is anatomically sound
    d. That a damage to the facial nerve injury is a potential hazard
    e. To undertake radical mastoidectomy to ensure complete removal of cholesteatoma

3. Fibre delivered laser energy is a most suited in cholesteatoma surgery because
    a. It can be delivered with a 600 µm robust fibre which provides a tactile feedback.
    b. It can be steered ‘round the corner’
    c. It can be safely used to vaporise oedematous mucosa or granulations in the vicinity of the facial canal
    d. It can be used to vaporise the adherent layer of cholesteatoma without causing movement of the ossicles
    e. It can be bounced off the otological mirror to reach medial surfaces of ossicles

4. The KTP laser is most suitable in cholesteatoma surgery because
    a. It can be delivered through a 200 µm fibre
    b. It operates in the visible spectrum of the radiation and thus it can be easily seen
    c. It can be used even in the presence of active bleeding to achieve haemostasis since its energy is maximally absorbed by haemoglobin in blood
    d. Its energy is maximally absorbed by blood in the blood vessels, thus resulting in bloodless surgery which provides a superior view of the operating site.
    e. All of the above

5. The Belfast Rules of Thumb
    a. Is a useful measure of surgical outcome since it correlates well with patients perspective of satisfactory hearing improvement
    b. It requires that the improvement in the operated ear be within 15 dB of the unoperated ear
    c. It also requires that the hearing threshold should be within 30 dB on the operated side
    d. It is necessary to satisfy only one criterion, not both
    e. All of the above

6. In cholesteatoma surgery
    a. The foremost aim is to remove the disease completely
    b. The secondary aim is to preserve the ossicular chain integrity to ensure a good hearing outcome
    c. The two aims are mutually exclusive when using cold instrumentation
    d. An instrument which solves the conflict, allowing removal of cholesteatoma and at the same time

Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery, edited by V. Oswal, et al., Kugler Publications, 2014. ProQuest Ebook Central,

   preserve the integrity of the middle ear component of the hearing is an advance on the current conventional instrumentation
   e. Laser is such an instrument
   f. All of the above

7. Safe use of laser in cholesteatoma surgery depends on
   a. Established expertise in the middle ear surgery with conventional cold instrumentation
   b. Avoiding its use in the vicinity of the facial canal, fistula of the lateral canal and the dura
   c. Avoiding its use on eroded ossicles or on thin superstructure of the stapes
   d. The otological mirror without any scratches
   e. All of the above

8. The Orthogonal view is
   a. View obtained of the medial surfaces of the ossicles using an otological mirror
   b. A direct lateral view of the middle ear structures
   c. Is obtained by approaching the space between the tympanic segment of the facial nerve medially and the ossicles laterally through the sinodural angle and the posterior tympanotomy
   d. A view of the medial surfaces of the ossicles obtained by approaching through the space between the tympanic segment of the facial nerve medially and the ossicles laterally
   e. A non-echo-planar imaging (non-EPI)-based diffusion-weighted (DW) magnetic resonance imaging (MRI) which identifies any residual or recurrent cholesteatoma after the surgery, thus providing a concrete basis for second look procedure

9. A combination of laser cholesteatoma surgery and postoperative non-EPI DW MRI
   a. Is a step forward in achieving a better hearing result
   b. Is a step forward in a complete clearance of cholesteatoma with only one surgical procedure
   c. Has a potential to avoid routine second look surgery
   d. Requires further controlled clinical trials for it to become a new standard in the management of cholesteatoma surgery
   e. All of the above

Chapter 35

Laser myringotomy

B. Sedlmaier and S. Jovanovic

1. Introduction

Secretory otitis media (SOM), a common otological condition in children, usually results from impaired middle ear ventilation. Surgical intervention is required in cases which fail to respond to medical management. Ventilation of the tympanic cavity by myringotomy, with or without tympanic drainage, is the treatment of choice (Politzer, 1869; Armstrong, 1954). The prevalence of SOM depends on the age of the child and season. It ranges between 3.1% and 36% (Black, 1984; Midgley *et al.,* 2000).

Therapeutic ventilation following conventional myringotomy is inadequate since the incision heals in a day or two. The healing is prolonged by insertion of a ventilation tube (VT), which has an average indwelling time of four to six months. This prolonged ventilation time has certain disadvantages: some patients may develop chronic otorrhoea; the VT may lead to permanent perforation, tympanosclerosis, atrophic scar and even cholesteatoma (Buckingham, 1981; Gates *et al*., 1998; Golz *et al*., 1999).

In general, the optimum ventilation time for complete resolution is regarded as being approximately three weeks (Armstrong, 1954).

A number of studies indicate that laser myringotomy is a feasible option to simple myringotomy with or without the use of a VT (Silverstein *et al*., 1996; Sedlmaier *et al*., 1998a; 2001). The ventilation time of the middle ear is determined by the diameter of the myringotomy perforation and, to a lesser extent, by the thermal effects of the laser on the tympanic membrane (Buckingham, 1981; Jovanovic *et al*., 1995a; Sedlmaier *et al*., 2001). By choosing an appropriate laser with certain parameters and modes of application (Goode, 1982; Jovanovic *et al*., 1995a; Silverstein *et al*., 1996), it is possible to create a myringotomy perforation of adequate size with a single laser application in topically anaesthetised eardrum. The three-week patency is followed by spontaneous closure without scar formation (Sedlmaier *et al*., 2001; 2002).

Alternative methods, such as heat myringotomy and mono- or bipolar electrothermal myringotomy, do not have the same precision and are less safe in their application. Furthermore, their application is restricted when using a topical anaesthetic because they require a longer exposure time on the tympanic membrane (Saito *et al*., 1978; Tolsdorff, 1998).

2. Suitable laser and application systems

The CO_2 (10.6 µm) and Er:YAG (2.9 µm) lasers are suitable for laser myringotomy due to their irradiation effects in the tissue (Goode, 1982; Pfalz, 1995). Water molecules, the main component of biological tissue, show a high absorption coefficient to these wavelengths. In a focused mode, the thermal effect of the CO_2 laser will

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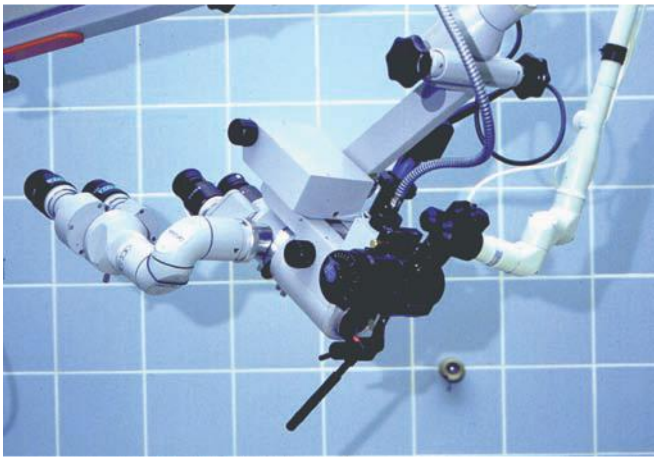


Fig. 1. Acuspot™ 712 micromanipulator.

vaporise tissues of the tympanic membrane. The oligothermal pulsed Er:YAG laser has a photoablative effect owing to its short pulse duration. In the past few years, both lasers have been applied in stapes and middle-ear surgery due to their controlled tissue penetration depth (Jovanovic *et al.*, 1993; Pfalz, 1995).

The CO_2 laser has several advantages over the Er:YAG. Computer-guided scanners can be used (SurgiTouch™ 780 A Office, ESC-Scharplan, Tel Aviv) for selecting the size and shape of the scan-area. In addition, highly precise micromanipulators (*e.g.*, Fig. 1; Acuspot™ 712, ESC-Scharplan, Tel Aviv) are available that can be used in combination with the scanners. With the use of these accessories it is possible to create a laser myringotomy of sufficient size with just one, or sometimes, more than one application. Moreover, the CO_2 laser has an adequate haemostatic effect on the blood vessels of the tympanic membrane so that the procedure is usually bloodless. The CO_2 laser has a very high margin of safety and higher power levels can safely be used in cases of marked thickening of the eardrum and tympanic effusion.

With the Er:YAG laser, an adequate perforation size is achieved by the application of several juxtapositioned focused pulses. However, the poor haemostatic effect makes repeated application difficult because of bleeding from the margins of the perforation (Sedlmaier *et al.*, 2000). A laser energy of 100 mJ per pulse should not be exceeded because of the risk of acoustic trauma to the inner ear. At the time of writing, no scanner system is available for the Er:YAG laser.

The CO_2 is the laser of choice for tympanic membrane application. Other clinical lasers, such as the Nd:YAG (1064 nm) and the Diode laser (812-945 nm) may also be suitable for use in the tympanic membrane. However, due to their tissue penetration depth they should be used with caution, and only in the contact mode with a pre-carbonised bare fibre (D'Eredità *et al.*, 2006).

3. Equipment for laser myringotomy

3.1. Micromanipulator

The micromanipulator used for laser myringotomy should have a precise beam profile and exact beam focusing. The Acuspot™ 712 fulfils these requirements. A laser beam with a spot diameter of 200 µm yields a high power density and reduces collateral thermal effects. A micromanipulator connected to an operating microscope is technically more complicated to use, but it provides a three-dimensional microscopic view and facilitates mechanical manipulation of the tympanic membrane.

3.2. Otoscope

The CO_2 laser otoscope Otoscan™ (Fig. 2; ESC Scharplan, Tel Aviv) consists of a mirror system with an integrated video camera. Specula of varying lengths and diameters can be used as appropriate. The diameter of the focused laser beam is about 400 µm. The otoscope is used in conjunction with a computer-guided scanner.

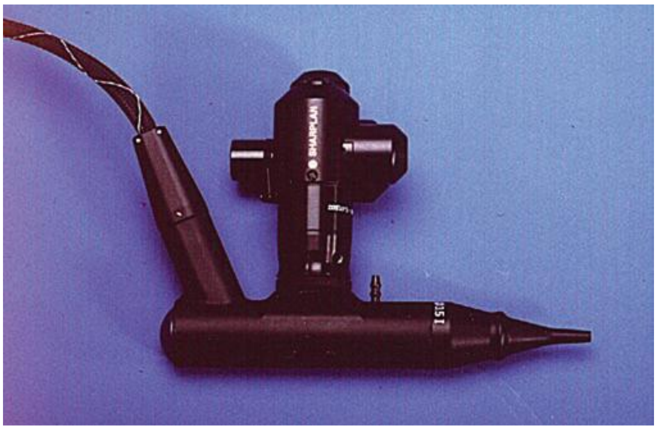


Fig. 2. CO_2 laser otoscope Otoscan™ (ESC Scharplan, Tel Aviv, Israel) consists of a mirror system (centre), a videocamera (left) and ear speculum attachments of various sizes (right). On top of the otoscope is the computer-guided scanner, to which the articulated mirror arm of the laser is connected.

3.3. Scanners

Scanners suitable for CO_2 laser application in the tympanic membrane are those that move the focused laser beam over a defined area by means of computer-guided rotating mirrors. In the system recently introduced, the laser beam describes a spiral figure that homogeneously irradiates the individual parts of the scanned area. The SurgiTouch™ 780 office system is incorporated into a CO_2 laser (40C, ESC-Sharplan, Tel Aviv, Israel) and can be combined with the Acuspot™ 712 micromanipulator as well as with the Otoscan™ otoscope. The diameter of the scanned area can be adjusted from 1-3 mm and the applied energy level can be set from 1-40 W. The pulse duration (30-300 msec) is automatically set by the system, and is dependent on the diameter of the scanned area.

4. Surgical technique

Prior to laser treatment, the auditory canal is cleansed and topical anaesthetic is applied to the tympanic membrane. A 16-32% tetracaine-based isopropanol solution is carefully infused into the external auditory canal so that no air bubbles are trapped, which could prevent its contact with the tympanic membrane. A small cotton pledget or a thin wick made of Merocel (Pope Ear Wick™, Merocel Surgical Products, Mystic, CT) is placed in the auditory canal to ensure that the anaesthetic remains in close contact with the tympanic membrane for about 30 minutes. The cotton pledget absorbs any excess anaesthetic agent and avoids the need for suction prior to myringotomy.

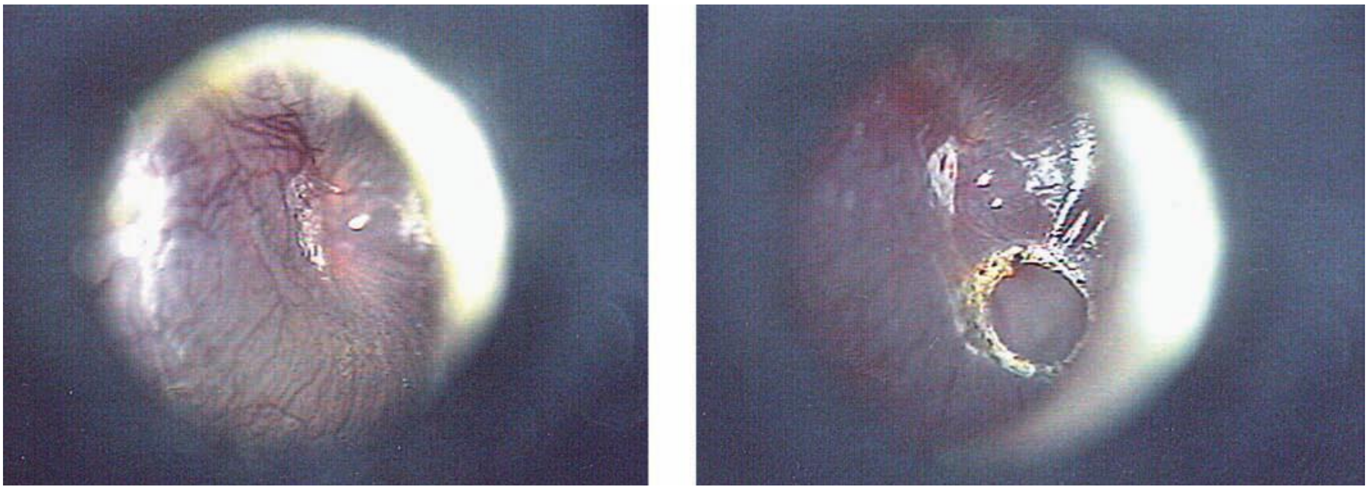
The myringotomy perforation is typically made in the anterior-inferior quadrant, avoiding irradiation of the umbo and the annulus. It may be necessary to undertake myringotomy in the posterior-inferior quadrant if the auditory canal is narrow or if its anterior wall is prominent. The laser energy level should be reduced in cases of equivocal tympanic effusion. The laser beam should be optimally focused when using the otoscope, as well as when using the micromanipulator. The focal plane is adjusted by altering the distance between the target tissue and the application system. The optimum focal length is that which corresponds to maximal visual acuity.

When using the operating microscope in conjunction with the micromanipulator, the highest magnification should be chosen at which to adjust the focal plane. The pilot beam circumscribes the selected scan area, the diameter of which varies according to the indication.

As a rule, tympanic membrane perforation is achieved in the first laser application using the parameters described earlier. In the presence of marked thickening of the eardrum, several applications may be required. In cases of a secretion-filled tympanic cavity, if the desired perforation diameter is not attained after the first laser application, the same site may be subjected to several strikes until the size of the perforation is adequate. In cases of an air-filled tympanic cavity, the perforation diameter can be enlarged by ablating the perforation margin without the scanner. Alternatively, the scanner should be used at its smallest scan diameter in order to avoid accidental strikes to the promontory. When the scanner is used with the otoscope, the following settings should be selected: 10 W power level, 1 mm scan diameter, 50 msec pulse duration. When it is used with the Acuspot™ micromanipulator, the settings are: 10 W, 1 mm, 60 msec. When the scanner is not used, a low power level of 2 W and a short pulse duration of 50 msec should be applied.

Irradiation of the promontory at these parameters will not damage the vestibulocochlear organ (Bonabi et al., 2008), but can lead to pain because the middle ear mucosa is not anaesthetised. Smoke generated by the micromanipulator should be removed between laser applications. The Otoscan™ otoscope has a built-in ventilator for removing the laser plume.

In principle, CO_2 laser myringotomy can be performed without scanners or an otoscope, and with micromanipulators other than the ones mentioned here. The most important parameter is the power density (W/cm^2) applied to the tissue. An effective power density of about 2000 W/cm^2 would be required for perforating a normal human tympanic membrane. The diameter of the focused laser beam is peculiar to each micromanipulator. When using a focused laser beam without a scanner, a short pulse duration (*i.e.*, 50 msec) should be selected. In order to achieve the desired diameter of the laser myringotomy, several contiguous laser applications are required at the margin of the perforation.



A. B.

Fig. 3. Secretory otitis media. A. Right-sided secretory otitis media prior to laser myringotomy. B. CO2 laser perforation (diameter: ~ 2 mm). Coagulation traces are visible at the perforation margins.

Defocusing the laser beam to enlarge the diameter of the irradiated area leads to a reduction in the power density in the tissue, proportional to the square of the radius of the irradiated area. Laser energy must be considerably increased in order to attain an effective power density. Defocusing to an area of 2 mm would necessitate a power level of about 60 W for an effective power density. Irradiation of the stapes footplate at this power level can lead to inner ear damage. A power setting of 60 W at a pulse duration of 0.05 seconds yields an energy of 3 J per pulse (J = W x second). As Jovanovic *et al*. (1993) showed in laser stapedotomy experiments in animals, a total energy of 3 J and above can cause irreversible inner ear damage when applied to the basal spiral canal of the cochlea of guinea pigs. In addition, defocusing makes the laser beam profile imprecise, which in turn reduces its effectiveness for creating perforations.

For these reasons, computer-guided scanners, which enlarge the irradiation area by moving the focused laser beam, should be given preference over defocused laser-beam application.

5. Indications

5.1. Secretory otitis media

Childhood and adult SOM is a sequela of eustachian tube (ET) dysfunction. Children under the age of four years often have persistent middle-ear effusion following acute otitis media. If the medical and expectant regime fails after a waiting time of eight to ten weeks, surgical ventilation of the middle ear is carried out with the CO_2 laser via the tympanic membrane. In children, the surgery is often performed under a topical anaesthesia, unless the adenoids are to be removed at the same time.

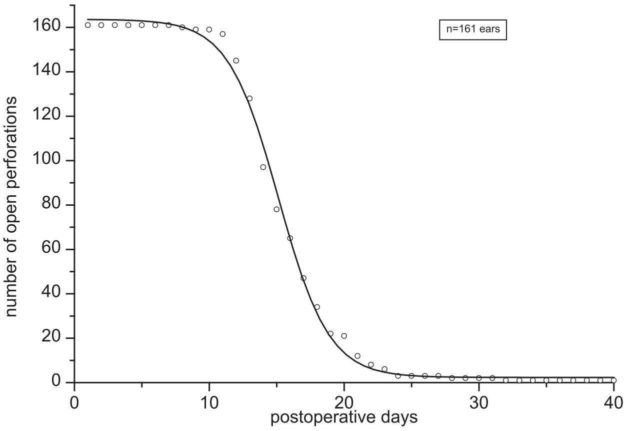


Fig. 4. Graphical display of the healing course of laser myringotomies (power: 12 W, pulse duration: 180 msec, scan diameter: 2.2 mm, perforation diameter: ~ 2 mm) in 81 patients (159 ears). The average ventilation time was 17 days (min.: 8 days, max.: 37 days).

Perforations smaller than 2 mm in diameter do not allow adequate ventilation time. A minimum perforation diameter created by the CO_2 laser should therefore not be less than 2 mm (Fig. 3 A,B). Myringotomy perforations of 2 mm in di-

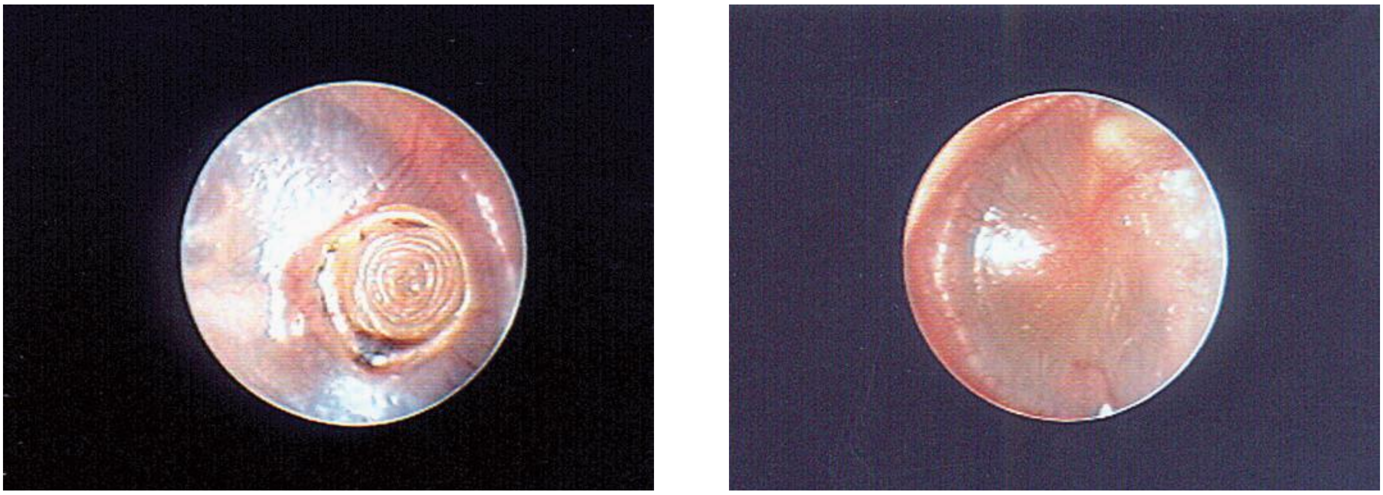


Fig. 5. Healing of laser myringotomy perforations. A. Healing three weeks postoperatively. The perforation is closed by an onion-skin-like membrane made of keratinised material. B. Four months after CO_2 laser myringotomy.

ameter generally close after a mean of 17 days (Fig. 4) and heal progressively without scar formation (Fig. 5A,B). This treatment time was shown to be adequate on the basis of previous experience (Jovanovic *et al.,* 1995a; Silverstein *et al*., 1996). In cases where SOM is associated with obstructed nasal breathing, the authors advocated CO_2 laser myringotomy, together with adenoidectomy as the primary surgical intervention. Any subsequent recurrence of effusion is treated by CO_2 laser myringotomy under topical anaesthesia. A second relapse is treated by VT insertion.

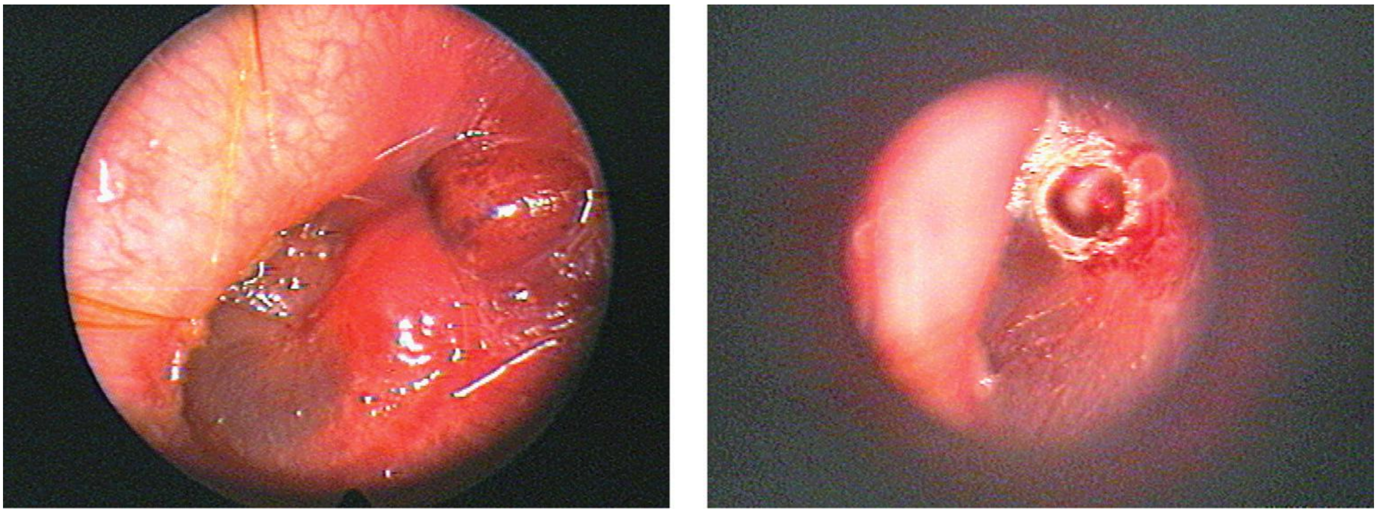
Myringotomy can be performed using an otoscope or a micromanipulator. Using the CO_2 laser otoscope, Otoscan™, a power setting of 12 W and a scan diameter of 2.2 mm are applied. A pulse duration of 180 msec is automatically set by the system. Using the Acuspot™ 712 micromanipulator connected to the operation microscope, a power level of 10 W and scan diameter of 2.2 mm are selected. The system automatically sets a pulse duration of 260 msec. In cases of unequivocal middle-ear effusion or thickening of the tympanic membrane, the power level of the Otoscan™ otoscope can be increased to 15 W and that of the Acuspot™ 712 micromanipulator to 13 W. For a perforation diameter of 2 mm, the scan area would be 2.2 mm using either system.

5.2. Acute otitis media with vestibulocochlear complications

Acute otitis media (AOM) is a bacterial infection secondary to a viral infection. In rare cases, vestibulocochlear complications can occur with hair-cell function impairment of the auditory and vestibular systems. Toxic damage through bacterial products is assumed. Myringotomy is performed to treat this condition. More serious complications, such as acute inflammatory facial nerve paralysis, mastoiditis, or intracranial extension of the bacterial infection must be managed by mastoidectomy.

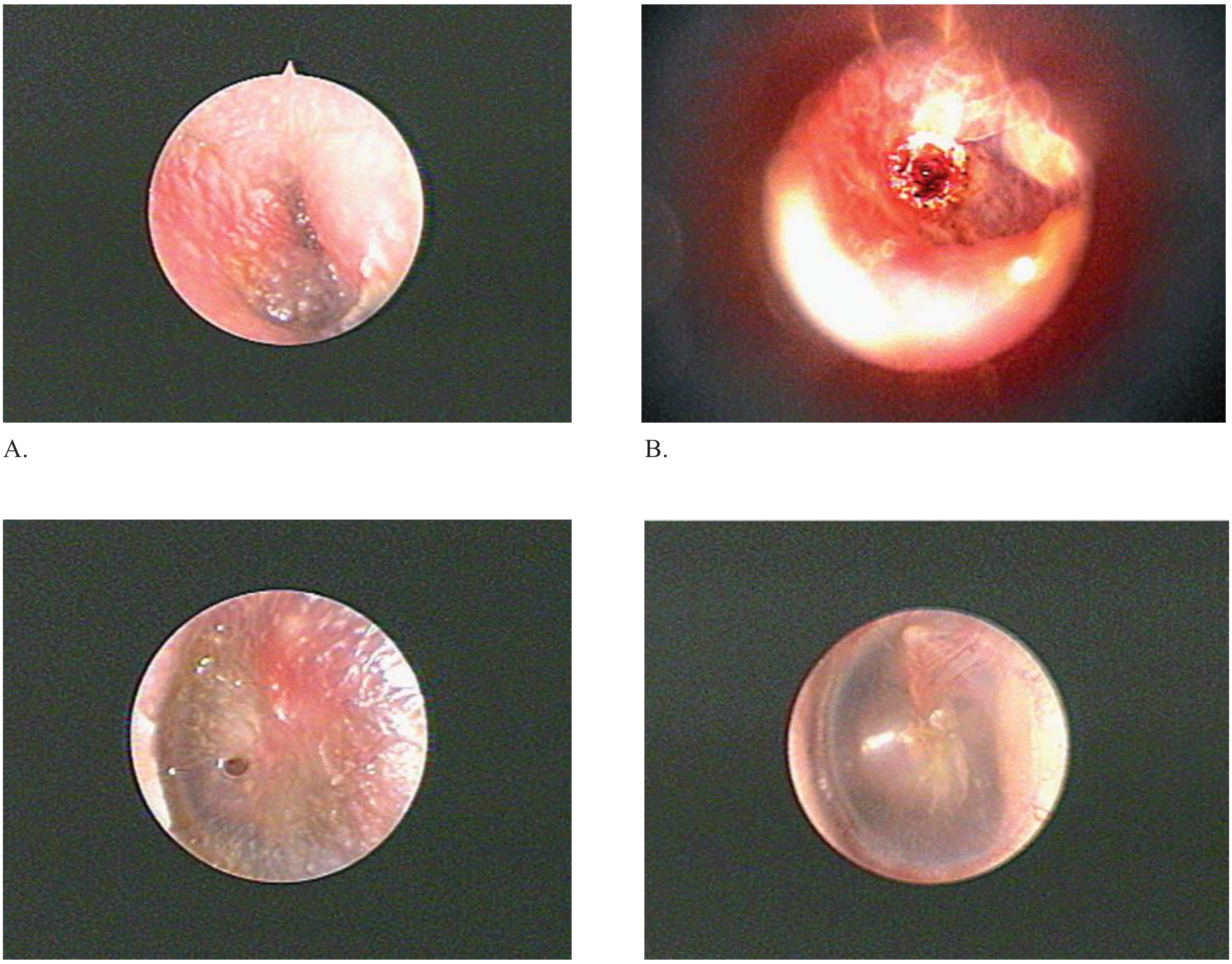
When acutely inflamed, the tympanic membrane is very often markedly altered, thickened, and covered with fluid-filled blisters (Fig. 6A), which will influence the effects of the laser on the tympanic membrane. If possible, the perforation is made in the anterior-inferior quadrant (Fig. 6B). In most cases, a shorter ventilation time than that needed for secretory otitis media is adequate, and thus a scan diameter of 1.6 mm is used. When using the Otoscan™ otoscope, the power level is set at 20 W and the pulse duration at 80 msec. For the Acuspot™ micromanipulator, a power setting of 20 W and a pulse duration of 110 msec is recommended. After creation of the laser perforation, the appropriate antibiotic therapy is prescribed.

Laser myringotomy as the primary therapy in uncomplicated AOM to prevent persistent tym-



A. B.

Fig. 6. Acutely inflamed tympanic membrane (A). CO_2 laser myringotomy under topical anaesthesia (B). A coagulation zone can be seen at the margins (perforation diameter: ~ 1.2 mm).



A. B.

C. D.

Fig. 7. Acute otits media. A. Bulging ear drum. B. Laser myringotomy. C. One week postoperatively. D: Two months postoperatively.

panic effusions and to reduce multiple courses of antibiotics is presently being investigated at our institute (Fig. 7A-D).

5.3. Acute eustachian tube dysfunction

Acute ET dysfunction is predominantly caused by acute inflammatory oedema of the ET ostial and luminal mucosa. Acute viral infection or allergy is a possible cause of the inflammation. Prolonged low tympanic pressure leads to fluid accumulation. Immediate operative ventilation of the middle ear is rarely indicated. If the initial medical regime fails, or when a rapid improvement in hearing is indicated (*e.g.*, only functioning ear), laser myringotomy is performed using the same parameters as those used in the treatment of secretory otitis media. The power level should be reduced when treating patients with equivocal effusion.

5.4. Barotrauma

Barotrauma is the result of a sudden change in ambient pressure in conjunction with reduced ET function. There is an acute, painful decrease of pressure in the middle ear with protrusion or retraction of the tympanic membrane. Barotrauma may result from air travel, a rapid altitude change in the mountains, or diving. The recommended conservative management is to re-duce the mucosal swelling of the nose and to administer an analgesic. The painful symptoms can be relieved immediately by CO_2 laser myringotomy under topical anaesthesia. The condition requires only short-term ventilation of the middle ear. To create a perforation of 0.8 mm in diameter, the following settings are used with the Otoscan™ otoscope: 10 W power level, 1-mm scan diameter, and 50-msec pulse duration. The parameter for the micromanipulator is a 10-W power level and a 60-msec pulse duration at the same scan size.

5.5. Transtympanic tympanoscopy

Inspection of the middle ear is indicated in cases of sudden deafness, which may be due to rupture of the round window membrane, displacement of a prosthesis, etc. Laser myringotomy under local infiltration anaesthesia allows insertion of a 1.7-mm rigid endoscope (0°, 30°, 70°) or dedicated flexible micro-optics (Fig.8) (Kakahata et al., 2004).

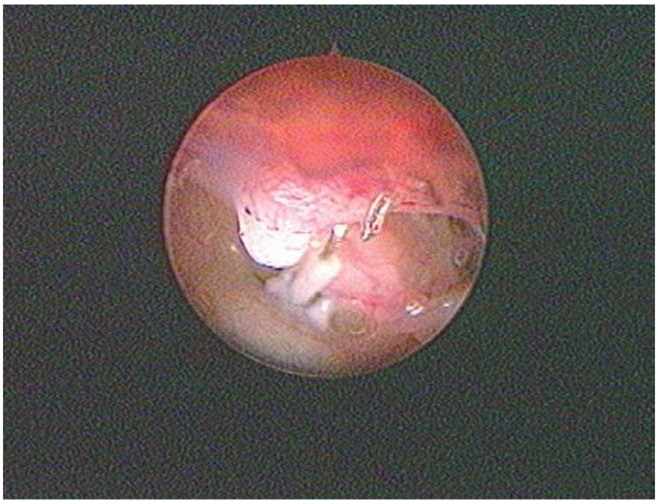


Fig. 8. Laser myringotomy under local infiltration anaesthesia allows insertion of an 1.7-mm rigid endoscope (0°, 30°, 70°) for an inspection of the middle ear. Endoscopic image of a platinum-Teflon stapes prosthesis five years after CO_2 laser stapedotomy with renewed, equivocal conductive deafness. The prosthesis does not appear to be dislocated.

Moreover, medication can be applied locally to the round window membrane using laser myringotomy. The tympanic tube orifice as well as the caudal parts of the sound-conducting apparatus can be inspected through a perforation in the anterior-inferior quadrant. The round window membrane can be seen in most cases through an opening in the posterior-inferior quadrant. The Otoscan™ otoscope is used at a power level of 10 W and pulse duration of 270 msec; the Acuspot™ micromanipulator is set at a 10-W power level and a 360msec pulse duration. A low power setting should be chosen because no secretion is present in the middle ear in these indications. The scan diameter is 2.6 mm for both systems.

6. Discussion

Ventilation dysfunction of the tympanic cavity is the cause of many acute and chronic middle-ear pathology. In childhood, ventilation problems of the middle ear are frequent, due to recurrent mucosal infections and enlargement of the lymphoepithelial pharyngeal and palatine tonsils. Persistence of this problem can lead to chronic inflammatory middle ear disease.

The most important therapeutic goal is to restore middle ear ventilation. If medical treatment proves unsuccessful after a period of eight to ten weeks, surgical intervention is advised. Simple myringotomy, consisting of an incision in the tympanic membrane, is inadequate, as it generally closes within 48 hours. VT insertion is usually unsatisfactory as it has an average in-dwelling time of four to six months in the tympanic membrane. This duration is too long and may lead to recurring or chronic otorrhoea, scarring, and atrophy of the tympanic membrane and tympanosclerosis (Buckingham, 1981; Gates *et al*., 1998; Golz *et al*., 1999).

A period of three to four weeks is considered adequate for therapeutic ventilation (Armstrong, 1954). Laser myringotomy facilitates ventilation of the middle ear via a perforation, the diameter of which influences the closure time and, there-by, the duration of tympanic ventilation (Goode, 1982; Jovanovic *et al*., 1995a; Silverstein *et al*., 1996).

There are reports, that laser myringotomy without adenoidectomy could be less effective in the treatment of SOM than VT-insertion (Cotter *et al*., 2004).

Thermal myringotomy using a hot needle, described by Saito *et al*., and its successor, monopolar or bipolar electrothermal paracentesis, seem to delay healing (Saito *et al*., 1978; Tolsdorff, 1998). These procedures do not have the same precision as laser myringotomy and are painful due to the longer exposure time on the tympanic membrane. Therefore, their application under topical anaesthesia is restricted.

Compared to methods using conventional instrumentation, laser application on the tympanic membrane has the advantage of being a noncontact, relatively bloodless, and very precise therapy (Goode, 1982; Jovanovic *et al*., 1995a; Silverstein *et al*., 1996; Sedlmaier *et al*., 2001). The greater safety margin and accessories of the CO_2 makes it the laser of choice. Its irradiation can be applied to the tympanic membrane via either highly precise micromanipulators or dedicated laser otoscopes (Derowe *et al*., 1994; Jovanovic *et al*., 1995b; Sedlmaier *et al*., 1998b). Using computer-guided scanners, the diameter of the irradiated area can be preset according to the treatment indication. These systems enable tissue ablation without any significant thermal effects. Treatment can be performed under topical anaesthesia in adults, children, and even infants. Thus, the procedure may obviate the need for general anaesthesia in some interventions, particularly in young patients.

Other lasers employed in medicine, such as the Nd:YAG (1064 nm) and the Diode laser (812-945 nm), are suitable for tympanic membrane application due to their tissue penetration depth, effects in the tissue, and lack of absorption in blood-free fluids only using the contact mode with a preconditioned bare fibre (D'Eredità *et al*., 2006).

The recommended laser parameters for the specific indications are computed on the basis of predetermined perforation size and closure time, as well as on the presence of fluid behind the tympanic membrane. For SOM, a therapeutic ventilation time of about three weeks is desirable. An average ventilation time of about 17 days is provided by a perforation diameter of 2.0 mm at a scan size of 2.2 mm (Sedlmaier *et al*., 2001). This ventilation time seems adequate on the basis of previous experience. Larger perforations are particularly difficult to create in infants because the tympanic membrane as a whole is smaller and there is the risk of irradiating the annulus or the umbo. In a cohort of 81 patients (159 ears), 14.5% had recurrent effusion within a six-month follow-up period. This relapse rate is comparable to that associated with conventional operative procedures for transtympanic ventilation, particularly after establishing tympanic drainage (Gates *et al*., 1989).

In Europe, enlarged pharyngeal tonsils are attributed greater importance in the pathophysiology of SOM than in the USA. In the EU, recurrent acute ear inflammation and persistent tympanic effusion, even in the presence of some impairment of nasal breathing, are generally managed by surgical removal of the pharyngeal tonsils and adenoids in order to improve tube function and to reduce the focus of infection. In the USA, establishment of tympanic drainage is frequently the only therapeutic measure. At our institution, the indication for VT insertion is a recurrence of SOM.

In AOM, CO_2 laser myringotomy is indicated in the presence of vestibulocochlear complications. The inflamed tympanic membrane is often very thickened and altered; thus, perforation of the eardrum is not always accomplished with a single laser application. With increased layer thickness and decreased tissue pH, topical anaesthesia of the tympanic membrane is not as efficient as in cases of SOM or an unaffected tympanic membrane. Ongoing prospective and prospective-randomised studies in the USA and Germany are investigating the importance of la ser myringotomy in the primary therapy of AOM in order to prevent persistent tympanic effusion and to avoid multiple courses of antibiotics.

CO_2 laser myringotomy of topically anaesthetised tympanic membranes can result in the rapid and immediate relief of the symptoms in cases of acute tube dysfunction and barotrauma.

For endoscopic transtympanic tympanoscopy in adults, a bloodless perforation of 2.4 mm in diameter can generally be created using a scan area of 2.6 mm and a single laser application. A perforation of this size has a closure time of about six weeks.

CO_2 laser can also be used for de-epithelialization of smaller permanent tympanic perforations as an alternative to conventional myringoplasty (Bessler *et al.*, 2009).

CO_2 laser myringotomy is a new method in the surgical treatment of ventilation disorders of the middle ear. This relatively painless outpatient procedure, which can be performed under topical anaesthesia even in children, frequently replaces the VT, with a self-healing perforation that enables sufficient ventilation of the tympanic cavity. For long-term, chronically recurring dysfunction of the ET, the VT remains a method of choice.

Modern application systems, such as the CO_2 laser otoscope, Otoscan™, combined with scanners, facilitate the simple and fast performance of interventions in topically anaesthetised tympanic membranes for various indications.

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MCQ – 35. Laser myringotomy

1. Disadvantages of conventional myringotomy without insertion of ventilation tube include
   a. Premature closure
   b. Persistent patency without healing
   c. Infection
   d. Need to prolong patency with insertion of ventilation tubes
   e. Lack of control on the size of the perforation

2. Myringotomy using otoscan otoscope
   a. The size of the perforation can be controlled precisely to optimise ventilatory period
   b. Needs insertion of ventilation tube
   c. Healing is almost always with a scar
   d. Healing is almost always without a scar
   e. Requires large capital outlay

3. Otoscan allows
   a. Myringotomy as an office-based procedure
   b. Accurate placement of the perforation
   c. Bloodless vaporisation with single shot
   d. In thick membrane multiple shots can be carried out until the perforation is achieved
   e. All of the above

4. Otoscan technique can be used for
   a. Acute barotrauma
   b. Ventilating the middle ear even in cases of markedly collapsed tympanic membrane on to the promontory
   c. Acute otitis media
   d. Chronic secretory otitis media
   e. Myringitis

5. The healing of the perforation created by otoscan depends on
   a. The thickness of the tympanic membrane
   b. The presence of plaques in the tympanic membrane
   c. The size of the perforation
   d. Severity of the condition such as secretory otitis media
   e. Placement of the perforation

6. Perforation created by otoscan
   a. Is more prone to allow infection in to the middle ear
   b. Has clean-cut edges
   c. Is always achieved with single shot exposure
   d. Has a pre-determined diameter
   e. Is dependent on the power setting

7. Optimum ventilation time for chronic secretory otitis media is
   a. Three months
   b. Three weeks
   c. Six weeks

d. Twelve months
e. Varies from patient to patient

8. Average indwelling time for standard ventilation tube is
   a. Two months
   b. Six months
   c. Four to six months
   d. Varies from patient to patient

9. In laser myringotomy, the ventilation time is determined by
   a. The size of the myringotomy
   b. The type of laser used
   c. The power density of the laser
   d. The severity of the chronic secretory otitis media
   e. Thermal effect of the laser on the tympanic membrane

10. The *ideal* laser for myringotomy is
   a. Diode laser
   b. Er:YAG laser
   c. CO_2 laser
   d. Nd:YAG laser
   e. Pulse dye laser

11. Laser myringotomy perforation is *typically* made
   a. In the retracted part of the tympanic membrane
   b. In the lower half of the tympanic membrane
   c. In the postero-superior quadrant
   d. In the antero-inferior quandrant
   e. In the atrophic part of the tympanic membrane

12. *Ideal* diameter of the perforation should be
   a. 2mm
   b. 2.2mm
   c. 3mm
   d. 1mm
   e. There is no hard and fast rule

13. For uncomplicated *acute* otitis media the scan diameter of the perforation is
   a. The same as that for chronic secretory otitis media
   b. Less than that for chronic secretory otitis media
   c. Greater than that for chronic secretory otitis media
   d. 1.6mm
   e. 2mm

14. For acute barotrauma the scan diameter is
   a. 2mm
   b. 1mm
   c. 0.8 – 1 mm
   d. 04mm
   e. Varies according to the severity of symptoms

Chapter 36

CO_2 laser in stapes surgery

S. Jovanovic

1. Introduction

Since the rediscovery of stapes mobilisation by Rosen (1952) and the first description of stapedectomy by Shea (1958), a number of modifications have been reported in the literature in the surgical management of otosclerosis. The two principal methods are stapedectomy and stapedotomy.

In the past few years, stapedotomy has become a popular method due to the lower incidence of postoperative sensorineural hearing loss. Various authors (Marquet *et al.*, 1972; Smyth and Hassard, 1978; Fisch, 1979; 1982; McGee, 1981; Marquet, 1985; Causse *et al.,* 1985) have put forward its following advantages:

- significantly better postoperative preservation of bone conduction and lower rate of deterioration of hearing;
- better prosthesis stability with significantly improved air conduction; and
- reduced influence of prosthesis length on the integrity of inner ear function.

The fact that there have been numerous modifications in the technique for stapes surgery clearly shows that the ideal surgical procedure is still illusive. Mechanical instruments such as a drill or a perforator cannot create a precise, round stapedotomy. In fact, in some situations, these instruments can prove hazardous. For example, manipulations may result in accidental mobilisation of a partially fixed stapes (floating footplate), while a thin footplate may be fractured. In obliterative otosclerosis, perforation of a thick footplate with the drill may result in significant inner ear trauma due to vibrations.

2. Laser in stapes surgery

The role of lasers in stapedotomy is two-fold:

- to assist in the management of stapes in such a way as to ensure maximum preservation of the inner ear function; and
- to avoid potential damage to the residual middle ear structures.

Advocates of the laser technique testify that non-contact laser vaporisation of the bone covering the vestibule is less traumatic to the inner ear than conventional manual removal, or perforation of the stapes footplate. However, it should be emphasised that the use of lasers in stapedotomy may result in damage to the membranous inner ear structures, due to generation of heat from inadvertent absorption of irradiation energy.

3. Review of the literature

The thermal effects of several wavelengths (argon, KTP-532, and CO_2 lasers) have been used for stapes surgery in the continuous wave (cw)

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and superpulse (SP) mode. In 1980, Perkins, DiBartolomeo and Ellis used the argon laser for the first time. In 1989, following the development of precision micromanipulators, Lesinski (1989) successfully used the CO_2 laser in stapes surgery. Nevertheless, their effectiveness and safety remains controversial.* This led to scepticism over their application in stapes surgery.

Since the publication of our experimental and clinical studies confirming that CO_2 laser is suitable for stapedotomy (Jovanovic *et al.*, 1990; 1991; 1992a,b; 1993a,b; 1995a-c,e,g; 1996a,c; 1997a,b; 1999), this wavelength in the far infrared range has been increasingly accepted in ear surgery. Clinical studies have demonstrated that the CO_2 laser achieves significantly better hearing results. Compared with conventional surgery, the complication rate is lower (Lesinski, 1989; Lesinski and Stein, 1992; Lesinski and Newrock, 1993; Haberkamp *et al.*, 1996; Beatty *et al.*, 1997; Shabana *et al.*, 1999; Jovanovic *et al.*, 1995g; 1997a,b; Jovanovic *et al.*, 2004; Garin *et al.*, 2002; Motta and Moscillo, 2002). While the laser is useful in primary stapes surgery, it is an elegant tool in revision surgery where its beneficial effects are particularly noticeable.

In contradiction to laser applications with a micromanipulator attached to the microscope, the fibre transmission of argon and KTP lasers seem to offer some advantages in both primary and re-vision cases (Perkins, 1980; McGee, 1983; Nissen, 1989; Horn *et al.*, 1990; Rauch and Bartley, 1992; Vernick, 1996; Wiet *et al.*, 1997). The fibreoptic micro-handpiece (Endo-Otoprobe) (Horn *et al.*, 1990) has the advantage of reduction of energy concentration as the distance between the target and the tip is increased (Gherini *et al.*, 1993; Causse *et al.*, 1993). Thus, any possible damage to the inner ear due to the depth of penetration and temperature increase in the perilymph is minimised. Moreover, the use of the fibreoptic micro-handpiece facilitates vaporisation of the anterior crus, thus obviating the necessity of conventional instruments imparting mechanical force (Häusler, 2000).

More recent investigations show that novel pulsed laser systems (excimer, holmium:YAG, erbium:YSGG, erbium:YAG), which act almost as cold instruments but without associated mechanical manipulation, may prove to be efficient and safe alternative for stapes management.**

Of the pulsed laser systems, the Er:YAG laser seems to possess the most suitable wavelength for middle ear surgery. Due to the small size of solid laser systems, lasers can be incorporated directly into the operating microscope so that no additional device for transmission via an articulated arm is needed. The danger of mechanically induced maladjustment of the Er:YAG laser beam with the pilot beam is practically non-existent.

The tissue interaction of the Er:YAG laser is different from that of the CO_2 laser because of the characteristics of the wavelength and exposure time. While the continuously radiating CO_2 laser is suitable for use on the soft tissue as well as – if sharply focused – for vaporisation of thin bone structures (Jovanovic *et al.*, 1995c; 1996a,c), the Er:YAG laser mainly offers advantages in the treatment of bony structures (Nuss *et al.*, 1988; Charlton *et al.*, 1990; Pfalz, 1995; Pratisto *et al.*, 1996; Jovanovic *et al.*, 1995d; 1996a; 1997c; Nagel, 1997). However, as soon as bleeding occurs, the oligothermic Er:YAG laser radiation is completely absorbed by the blood and no longer reaches the target. Moreover, the measured sound level in Er:YAG laser application is higher, and may potentially result in inner ear trauma and tinnitus (Jovanovic *et al.*, 1995f; 1996a; 2000; Pratisto *et al.*, 1996; Häusler *et al.*, 1999). The pressure waves resulting from Er:YAG laser therapy can cause transitory or even permanent deterioration of the high frequencies, or tinnitus (Häusler *et al.,* 1999; Bretlau, 1999; and our own experience). Recent clinicial studies show that the Er:YAG laser stapedotomy is a safe and effective procedure, with no damage to the inner ear when strict adherence to the safety parameters is observed (Huber *et al.* 2001, Keck *et al.* 2002, Galli *et al.* 2005, Parrilla *et al.* 2008). Nevertheless the safety margin of the Er:YAG laser is far lower than the CO_2 laser. Thus, the current status of the erbium laser is that it is not suitable for stapes surgery with the safety level similar to that of the CO_2 laser.

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* (Lyons *et al.*, 1978; DiBartolomeo, 1981; Thoma *et al.*, 1981; 1982; 1986; Gantz *et al.*, 1982; Vollrath and Schreiner, 1982a,b; 1983a,b; McGee, 1983; Lesinski, 1989; 1990a,b; Lesinski and Stein, 1992; Lesinski and Newrock, 1993; Palva *et al.*, 1977; 1987; Silverstein *et al.*, 1989; 1994; McGee and Kartush, 1990; Bartels, 1990; Vernick, 1990; 1996; Horn *et al.*, 1990; 1994; Gherini *et al.*, 1990; Fischer *et al.* 1990; 1992; Jovanovic *et al.*, 1990; 1991; 1992a,b; 1993a,b; 1995a-g; 1996a-c; 1997a-c; 1998; 1999; 2000; Hodgson and Wilson, 1991; Pfalz *et al.*, 1991; Lim, 1992; Strunk *et al.*, 1992; Schönfeld *et al.*, 1994; Haberkamp *et al.*, 1996; Vernick, 1996; Wiet *et al.*, 1997; Shabana *et al.*, 1999).

** (Schlenk *et al.*, 1990; Segas *et al.*, 1991; Kautzky *et al.*, 1991; Fischer *et al.*, 1990; 1992; Jovanovic *et al.*, 1990; 1992a; 1995a,d,f; 1996a,b; 1997c; 1998; 2000; Hommerich and Hessel, 1991; Hommerich and Schmidt-Elmendorff, 1993; Pfalz *et al.*, 1992; Stubig *et al.*, 1993; Zrunek *et al.*, 1993; Schönfeld *et al.*, 1994; Pratisto *et al.*, 1996; Shah *et al.*, 1996; Nagel, 1996; 1997; Arnold *et al.*, 1996; Häusler *et al.*, 1999; Lippert *et al.*, 2001).

4. Experimental data

Published experimental studies on the feasibility of lasers for stapedotomy differ considerably with regard to their design, choice of method, and performance. We compared results obtained with cw and pulsed lasers and re-evaluated them by appropriate experimental and analytical methods. An experimental model was set up with the following aims:

- to create a perforation measuring 500-600 µm in diameter (referred to below as 'laser perforation');
- to determine the potential of damage to the inner ear; and
- to determine the ideal wavelength and its parameters to achieve the above objective.

The argon and CO_2 lasers at the cw and SP mode, and the three pulsed laser systems (excimer, Ho:YAG and Er:YSGG) were used.

4.1. Stapes perforation

Isolated human stapes and bovine compact-bone platelets were treated and the data analyzed to determine optimum laser wavelength and its parameters.

Argon laser

The suitability of the argon laser for stapedotomy is doubtful because of the lower absorption coefficient of the stapes for the argon beam. The effect of the argon is also dependent on the degree of pigmentation in the irradiated tissue, with the resulting poor reproducibility of the perforation diameter. This also manifests itself in the high total energy of about 2.7 J for laser perforation (Jovanovic *et al.*, 1996c).

CO_2 laser

The absorption of the CO_2 laser beam at the footplate is greater than that of the argon laser, resulting in higher effectiveness, better reproducibility, and lower thermal side-effects.

The optimum CO_2 laser parameters in the cw mode were found with the laser set at power densities of 16,000-24,000 W/cm² (spot size, 180 µm), delivering energy per pulse of 0.2-0.3 J. A multiple application technique with a pulse count of four to six applications results in adequately large perforations of 500-600 µm (Jovanovic *et al.*, 1996c). The total energy level ranges from 0.8-1.8 J. Neither the cw nor the SP mode show any appreciable difference in creating the laser perforation.

Further improvement in perforation quality and reproducibility could be achieved with the use of new scanner systems. Microprocessor-controlled movement of the focused laser beam delivering a power density of 80,000-88,000 W/cm² and a total energy of 0.8-0.9 J over a defined area creates a one-shot stapedotomy which results in a perforation diameter of 500-600 µm.

Pulsed lasers

The tissue-ablating effect of pulsed laser systems permits precise and controlled management of the stapes footplate by means of low and readily reproducible ablation rates. The extent of thermal side-effects at the footplate is lower compared to cw and SP laser systems.

Compared to the radiation of the excimer (λ = 308 nm) and Ho:YAG (λ = 2.1 µm) wavelengths, that of the Er:YSGG wavelength (λ = 2.78 µm) is more strongly absorbed by bone tissue. Therefore, the Er:YSGG laser not only requires a lower number of pulses (ca. 5), but also less total energy (0.5 J) to achieve a laser perforation. The somewhat lower ablation rate of the Ho:YAG laser needs ten pulses and approximately four times as much total energy. On the other hand, because of its low ablation rates, the excimer laser (308 nm) is not suitable for fenestration (Jovanovic *et al.*, 1997c).

Thus, of the pulsed laser systems examined, the Er:YSGG exhibits the highest footplate ablation rate and is therefore the most effective laser for stapedotomy. This is also confirmed by studies with the Er:YAG laser (λ = 2.94 µm), whose absorption properties, and thus footplate effects, are comparable to those of the Er:YSGG laser (Schlenk *et al.*, 1990; Pfalz *et al.*, 1992; Pratisto *et al.*, 1996; Nagel, 1997).

4.2. Functional and morphological changes in the inner ear

The laser effect following perforation of the basal convolution of the guinea-pig cochlea (cochleostomy) was examined as follows:

- the 'effective laser range' (power density, beam diameter, pulse duration, and total energy) was determined, to make a perforation of 500-600 µm in diameter;
- inner ear function was assessed with acoustic evoked potentials (compound action potentials (CAP)); and
- morphological changes in the organ of Corti were examined by scanning electron microscopy.

CO_2 laser

Using the CO_2 laser in the cw mode, an optimum power density of 16,000 W/cm² (energy, 0.2 J) was necessary to create a perforation of 500-600 µm. When the power density was increased fourfold, applications of single or multiple exposures of 50 msec duration (energy, 1 J) did not cause CAP changes. On the other hand, the SP mode, with peak pulse powers of 300 W and a pulse sequence of short single pulses of 90-120 µsec resulted in irreversible CAP alterations in 40% of the animals (Jovanovic *et al.*, 1999). Thus, it is clear that the margin of safety is much greater when the CO_2 laser is used in the cw mode.

The precise mechanism of damage to the inner ear in the SP mode remains unclear. It may be postulated that the high peak pulse power (peak pulse power density, ca. 10^6 W/cm²), emitted in short single pulses with different pulse sequences, leads to pressure waves in the cochlea, almost regardless of the average power setting. Clinical studies by other authors (Lesinski, 1989) have shown that lower peak pulse power in SP could be safer.

One of the sites of damage is the sensory and supporting cells of the organ of Corti, as demonstrated by histological and electron-microscopic studies. Application of the CO_2 laser in the SP mode altered the inner and outer hair cells in more than 40% of the guinea pigs. The changes included torsion and collapse of the stereocilia, and fusion of the stereocilia tips with giant cilia formation (Jovanovic *et al.*, 1996a). On the other hand, the cw mode showed no increase with the scanning electron microscope, even when the energy was increased to 2 J.

Pulsed lasers

The Er:YSGG laser was used with a setting of 85 mJ/pulse and a density of 36 J/cm², to create a footplate perforation of 500-600 µm. As many as five exposures were necessary. There was no change in CAP in any of the animals. Likewise, an increase in the repetition rate from 1-5 Hz did not cause any CAP alterations (Jovanovic *et al.*, 1995f). The energy level was then increased successively in three steps: five-, ten-, and 15-fold. A five-fold increase of energy did not show any alteration in CAP, while a ten-fold increase showed irreversible CAP changes, and a 15-fold increase eradicated CAP altogether. These results demonstrate safety of the Er:YSGG laser compared to the CO_2 laser for stapedotomy, supporting its usefulness as an optional wavelength for surgery.

With the Ho:YAG laser, an adequately large perforation could be achieved with at least ten applications of an energy of 210 mJ per pulse (energy density, 90 J/cm²; total energy, 2.1 J). These parameters caused a slight to an extreme irreversible CAP alteration in over 50% of the animals. Doubling of the pulse rate led to extreme, only partially reversible, CAP alterations in all animals. A five-fold increase in the pulse count (50 applications) caused loss of hearing in all animals. Thus, the Ho:YAG laser is not as well tolerated as the Er:YSGG in animal experiments, and only has a low margin of safety. Its application in stapedotomy would be unreliable and damaging for the inner ear.

Likewise, the excimer laser (308 nm; energy, 13 mJ/pulse; energy density, 5-7 J/cm²) appears to be unsuitable for stapedotomy, since high total energy was necessary (up to 52 J) and irreversible damage to the cochlea was registered even before perforation of the basal convolution (500 applications, total energy 6.5 J).

Studies using a scanning electron microscope showed no adverse effects on the guinea pig organ of Corti when the Er:YSGG laser was used. On the other hand, the Ho:YAG laser caused damage to the outer hair cells with the fusion of stereocilia and the formation of giant cilia leading to partial or total cell loss. The inner hair cells and supporting cells were normal. These morphological data show good correlation with electrophysiological measurements (Jovanovic *et al.*, 2000). These published results clearly demonstrate that, besides achieving efficient bone management, the Er:YSGG laser is very safe with regard to application. On the other hand, the Ho:YAG laser was not well tolerated in our animal studies, and its use in stapedotomy would be unreliable and traumatic for the inner ear. However, these results are only valid for the lasers examined in this study, since their applicability to other pulsed laser systems, particularly those with shorter pulse half widths, is still questionable due to possibly higher pressure impulses.

5. Equipment for CO_2 laser stapedotomy

5.1. CO_2 laser

One of the notable advantages of the CO_2 laser in stapedotomy is its high absorption in the perilymph. Since the energy is maximally absorbed within a few tens of microns at the surface (penetration depth of 10 µm), very little energy is conducted in the perilymph. Although the inherent property of the CO_2 wavelength is suitable for stapedotomy, the older equipment could not be used on account of the large spot size delivered by the micromanipulators.

5.2. Application systems (micromanipulator)

The laser beam of modern laser systems can now be focused with a high-precision micromanipulator to a spot diameter of about 180 µm at a focal length of 250 mm. Thus, a very high power density can be delivered over a very small surface area, which enables the precision surgery required for stapedotomy.

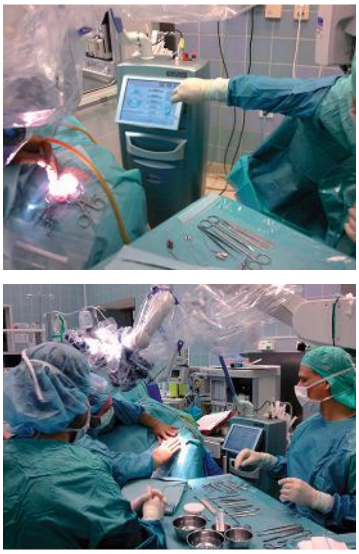


Fig. 1. Author's CO_2 laser set up for stapes surgery.

5.3. Scanner systems

When applying laser irradiation with microprocessor-controlled rotating mirrors, the so-called scanner systems (SurgiTouch™, Lumenis Inc., modified according to our recommendations), a spiral figure is traced within the defined pulse duration. This enables the CO_2 laser to achieve a high power density with minimal side-effects, even in large irradiation fields. At a working distance of 250 mm, the scanner can be set for irradiation fields of various sizes, depending on the anatomical variations and preselected perforation diameter. Irradiation fields of 0.5, 0.6, and 0.7 mm are suitable for stapedotomy. A radius of less than 0.5 mm or greater than 0.7 mm can be achieved with SurgiTouch™, but is rarely applied. Thus, a suitable selection of laser parameters basically enables a single-shot footplate perforation of preselected diameter. The laser beam is guided via a hinged mirror arm to a micromanipulator connected to the operating microscope, and is transmitted from there to the operating area: 250 mm proved to be the most favourable working distance (Fig. 1).

6. Effective and safe laser parameters for CO_2 laser stapedotomy

The thermal spread of CO_2 laser irradiation can be reduced by applying the laser energy in a single shot ('one shot technique') using SurgiTouch™. This accessory consists of a microprocessor-controlled rotating laser beam of high-

Table 1. Effective laser energy parameters for stapes surgery (AcuPulse TM CO_2 SurgiTouch TM Laser with the micromanipulator Acuspot 712, Lumenis Inc)

Anatomical structure	Real power (W)	Power density (W/cm²)	Pulse duration (s)	Mode	Diameter of irradiation (mm)	Number of pulses	Diameter of perforation (mm)
Stapedius tendon	2	8000	0.05	cw	0.18	2-3	
Incudostapedial joint	6	24000	0.05	cw	0.18	8-14	
Crura	6	24000	0.05	cw	0.18	4-8	
Stapes footplate	6	24000	0.05	cw	0.18	6-12	0.5 - 0.7
	or 20-22*	80000-88000	0.03, 0.04, 0.05	cw	ca. 0.5 , 0.6 or 0.7	1	0.5 - 0.7

Focal length: f = 250 mm; focal size: 0.18 mm (Acuspot 712®)

* Application of laser irradiation with rotating mirrors (SurgiTouch®)

Specified powers correspond to real powers at the end of the application system. Use of rotating application systems at the stapes footplate may require perforation enlargement by additional individual applications without a rotating laser beam (power: 6 W, pulse duration: 0.05 sec) power and short-pulse duration. It scans figures of different irradiation diameters. Based on data obtained from petrous bone preparations, a cochlea model, and animal experiments (Jovanovic *et al.*, 1995e; 1996c; 1999), effective parameters were determined for stapedotomy with the CO_2 laser (AcuPulse TM CO_2 SurgiTouch TM Laser with the micromanipulator Acuspot 712, Lumenis Inc.) (Table 1). The mode was continuous wave. A power setting of between 1 and 20 W and a pulse duration of 0.03-0.05 seconds were found to be the most effective settings for bone vaporisation with minimum thermal conduction. The power density at these settings ranged from 4000–80000 W/cm². These CO_2 laser settings deliver high-power density, but low single-pulse energy. A single laser shot with rotating mirrors can usually achieve precise footplate perforations of 0.5–0.7 mm in diameter. If necessary, the perforation diameter can be increased by additional single shots without the rotating beam. Applying a good beam profile enables optimal tissue results to be obtained with minimal thermal side-effects. Strict adherence to laser energy parameters minimises any risk to the middle and inner ear structures from thermal or acoustic stress.

If the scanner system is not available, several juxtapositioned single shots are applied in a circular fashion (‘multiple application technique’) with low power, short-pulse duration, and a small beam diameter.

7. Laser stapes surgery

7.1. Anaesthesia

CO_2 laser stapedotomy can be performed under local or general anaesthesia. We prefer general anaesthesia in most cases (90%), since surgical control is superior and does not require patient cooperation. This is of paramount importance, particularly in the elderly, who tend to react adversely to sedation. Similarly, general anaesthesia is preferable in overanxious patients. However, general anaesthetic has one inherent disadvantage: optimum positioning of the strut cannot be monitored as with local anaesthesia. However, on the whole, the benefits derived from general anaesthesia outweigh the disadvantages. On the otherhand, revision stapedotomy should be undertaken under local anaesthetic wherever possible, since a particularly difficult pathological condition may be encountered. For local anaesthesia, 6-10 ml 1% Xylocaine with 1:200,000 adrenalin is injected quadrant-wise into the cartilaginous auditory canal. Apart from the usual premedication with a benzodiazepine (7.5 mg midazolam preoperatively), some patients require additional intravenous sedation (*e.g.*, propophol sometimes combined with opioids) under the supervision of an anaesthetist. Laser surgery under local anaesthetic may not be possible in some patients who suffer from dizziness at the slightest manipulation of the ossicular chain (prosthesis).

7.2. Access to the surgical site

Access to the middle ear is obtained either endaurally or permeatally, according to the experience of the operator. After endaural incision, a tympanomeatal flap is raised. Any bony overhang is removed up to the oval window niche; so that the pyramidal process and part of the tympanic segment of the facial nerve are clearly visible (Fig. 2). The chorda tympani is preserved.

7.3. CO_2 laser stapedotomy

Application of the CO_2 laser is preceded by some test shots on a wooden spatula in order to ensure that the aiming beam is aligned with the CO_2 beam. Ablation of the tendon, incudo-stapedial joint, and suprastructures, and perforation of the footplate are then performed with the free-mode non-contact CO_2 laser beam.

Vaporisation of the stapedius tendon

The stapedius tendon is first vaporised with two or three single pulses at a low power of 2 W (power density 8000 W/cm²) and a pulse duration of 0.05 seconds (Fig. 3).

Separation of the incudo-stapedial joint

Vaporising the head of the stapes with eight to 14 single pulses of the laser beam at 6 W (power density 24,000 W/cm²) and a pulse duration of 0.05 seconds (Fig. 4) then separates the incudo-stapedial joint. Since the CO_2 laser beam does not strike perpendicular to the joint, the separation may not be complete. Any remaining tissue is severed with a curved needle.

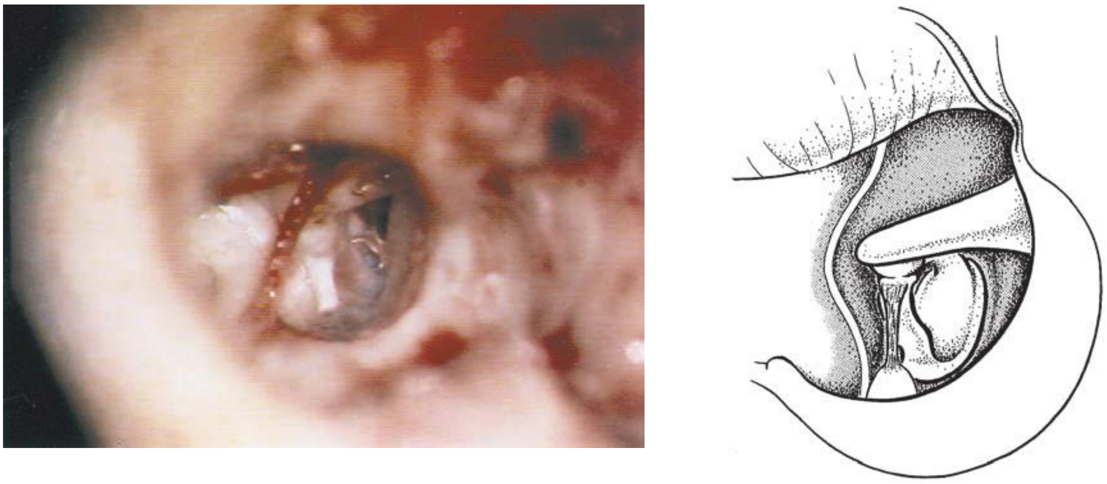


Fig. 2. Bony overhang is conventionally removed until the oval window niche; the pyramidal process and part of the tympanic segment of the facial nerve are clearly visible.

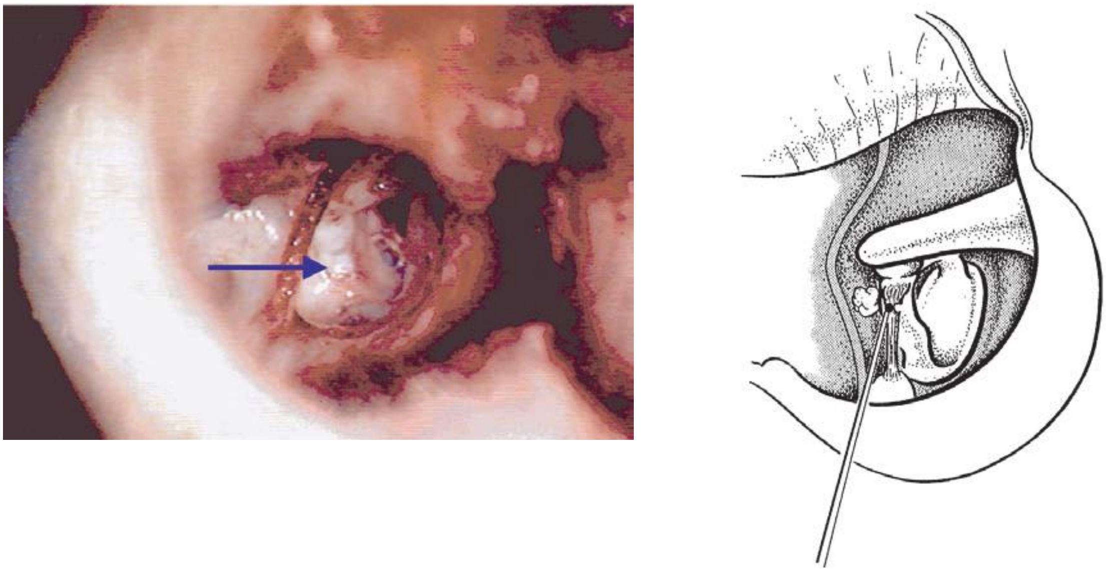


Fig. 3. The stapedius tendon is vaporised with two to three single pulses at low power of 2 W.

Vaporisation of the posterior crus

Vaporisation of the posterior crus requires four to eight laser strikes with a power of 6 W set at a pulse exposure of 0.05 seconds (Fig. 5). While severing the joint and the posterior crus with this relatively high laser power, care must be taken that the middle ear structures in the path of the beam and beyond the target (footplate, facial nerve canal, etc.) are not accidentally irradiated and damaged. Adequate protection is provided by filling the tympanic cavity with saline or by covering of the non-target structures with salinesoaked gelatine sponge (Gelita™, Spongostan™).

Vaporisation of the anterior crus

The anterior crus of the stapes is not usually accessible to the laser beam for direct strikes. Therefore, it is fractured with a hook. However, in some cases, the anterior crus may be partially visible. Protecting the non-target areas, the crus is vaporised with the CO_2 laser beam, using the same parameters as for the posterior crus. Should vaporisation be incomplete, the residual bone can be severed with a minimum of force, using a cold instrument. Footplate mobilisation or even partial or total footplate extraction is thus almost entirely avoided. The stapes superstructure is removed with the micro-forceps.

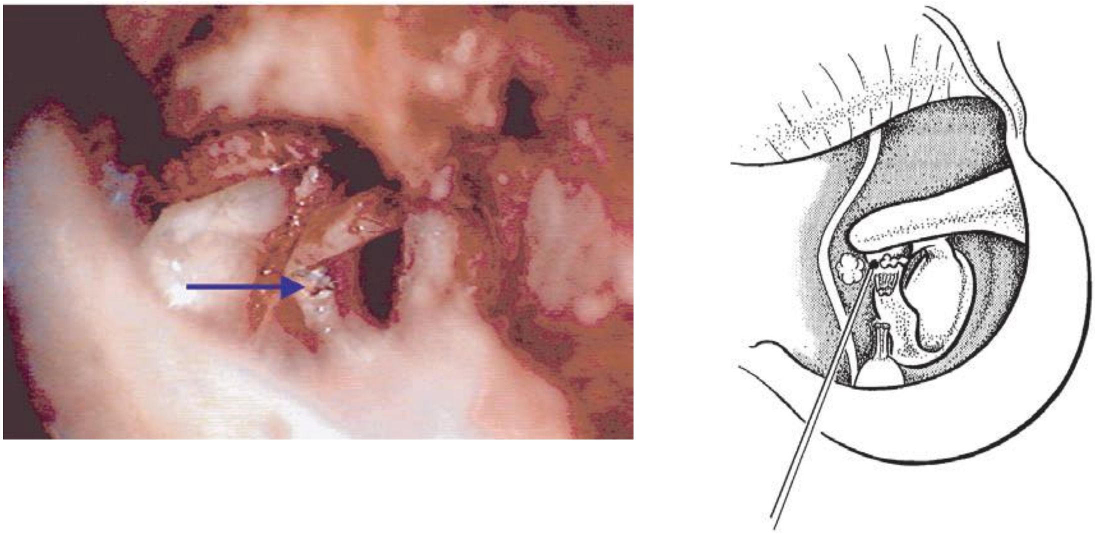


Fig. 4. Vaporisation of head of the stapes separates the incudo-stapedial joint.

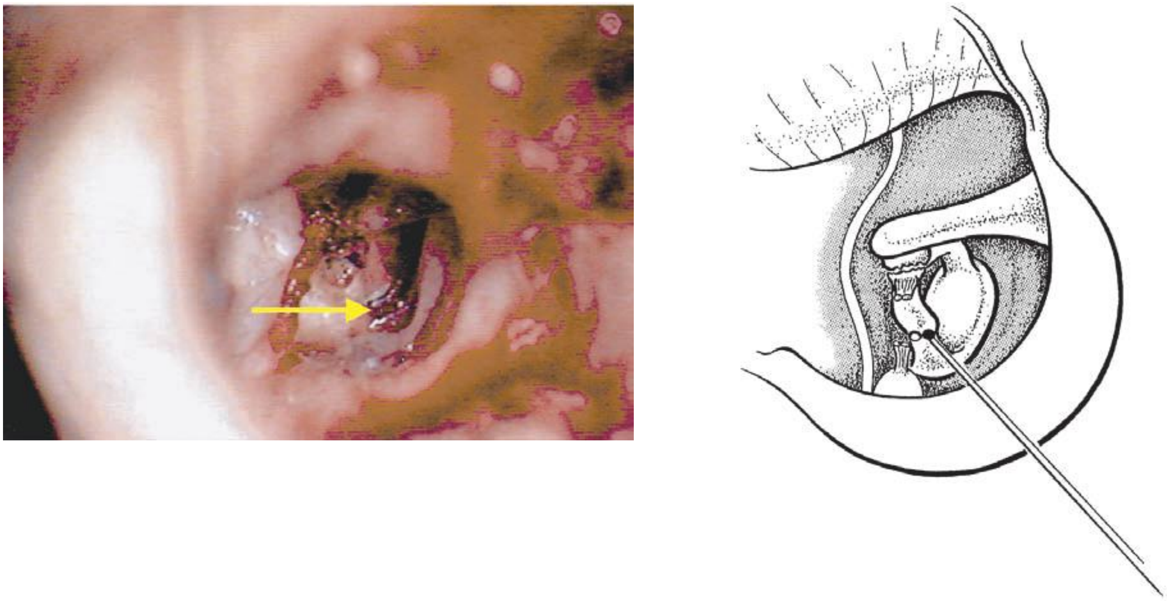


Fig. 5. Vaporisation of the posterior crus with four to eight laser strikes (6 W set at pulse exposure of 0.05 sec).

In our laboratory, the criteria and the feasibility of vaporisation of the anterior crus with a deflected laser beam was tested. The mirror for deflection must meet specific standards. The reflected image of the anterior crus must be clearly seen. It should not cause any distortion of the active CO_2 laser beam, should transmit it completely and without scattering. The deflected helium neon beam is then sharply focused onto the surface of the crus. The gold covered mirror of 0.8 mm in diameter, made in our laboratory, has not proved adequate for vaporisation of the anterior crus, and is thus not used in routine clinical practice.

Perforation in the footplate

The perforation created with laser should be circular, with a clean-cut edge. It is preferably carried out with a 'one shot' application of the laser energy, delivered with rotating mirrors (SurgiTouch™). The energy setting depends on the thickness of the footplate and the irradiation diameter of the scanning figure applied. In our experience, a power setting of

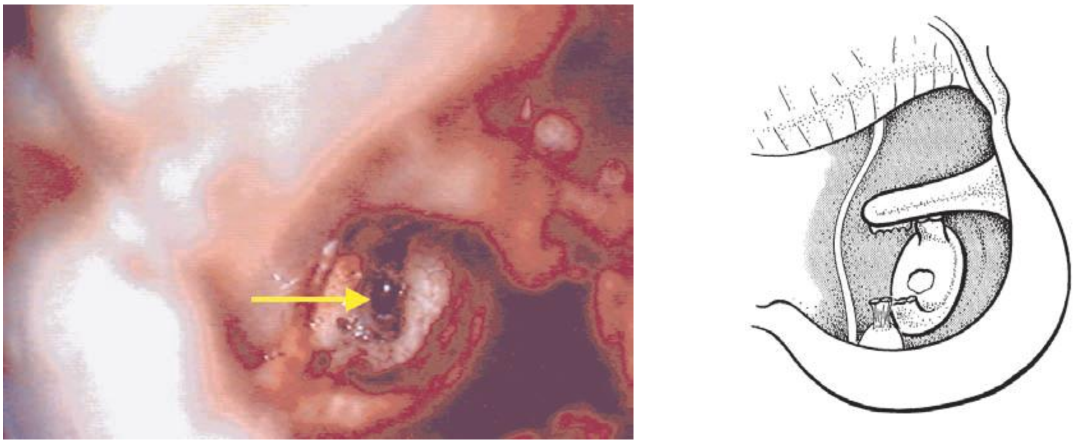


Fig. 6. Perforation of the footplate.

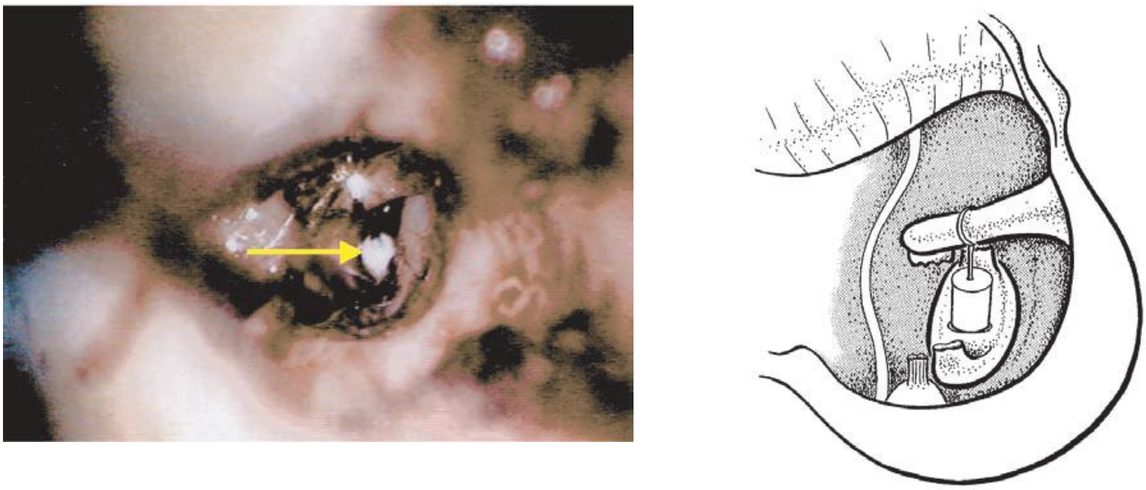


Fig. 7. Insertion of platinum Teflon piston.

20-22 W, with an exposure time of 0.03 and 0.05 seconds per pulse (Fig. 6), creates a round, clean perforation of 0.5–0.7 mm in diameter, in 90% of cases. In those cases in which the desired perforation diameter is not achievable with one shot, enlargement of the perforation is performed by additional laser applications without the scanner system.

When scanner system is not available, the perforation is achieved by the 'multiple-shot' application technique. Small areas are vaporised with a few juxtapositioned, slightly overlapping multiple shot applications of laser energy in a circular manner. With a beam diameter of 180 μm, the power for the multiple shot application technique is set at 6 W and the pulse duration is 0.05 seconds. A perforation of 0.5–0.7 mm is achieved with six to 12 applications, depending on the thickness of the footplate.

Care must be taken that the vestibulum is filled with perilymph in order to ensure adequate protection of the inner ear structures and to prevent damage by direct laser irradiation. If the perilymph is inadvertently aspirated from the vestibulum, no further laser irradiation should be applied to the footplate.

A platinum Teflon piston of 0.4-0.6 mm in diameter is then inserted into the perforation and secured to the incus neck. Finally, the oval niche is sealed with connective tissue or a blood clot (Fig. 7).

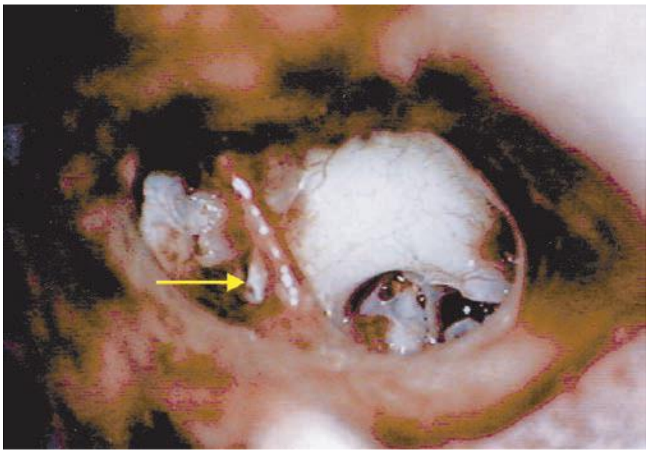
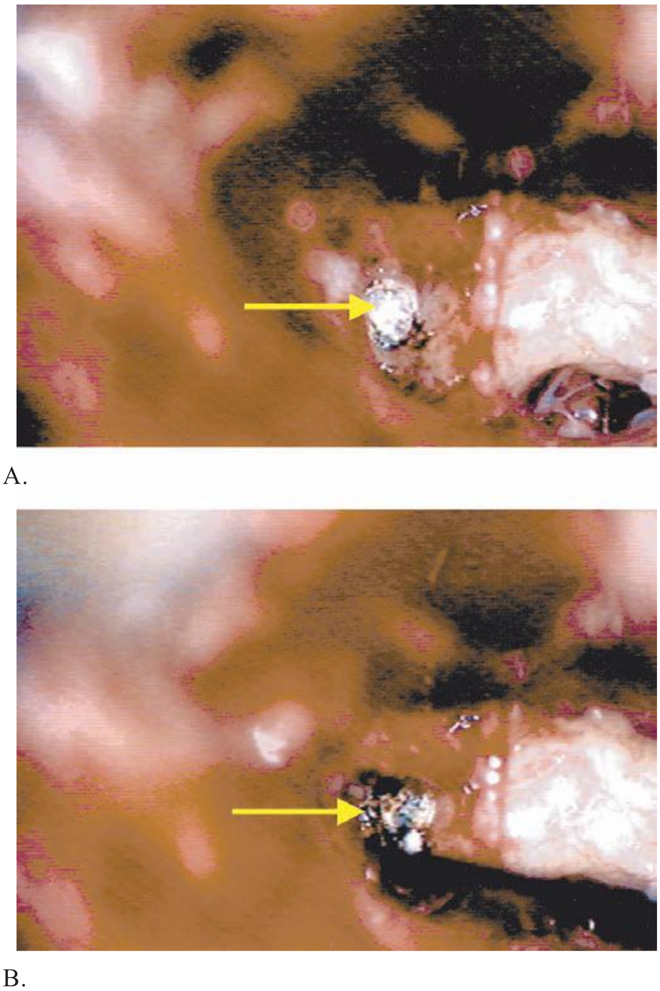


Fig. 8. Obliterative footplate.

8. Obliterative otosclerosis

The incidence of obliterative otosclerosis (Fig. 8) is between 2 and 10% of all cases (Schuknecht, 1971; Raman *et al.*, 1991; Hough and Deyer, 1993; Fisch, 1994). In our series, the incidence was 5%. Using a drill to perforate a thick footplate obliterating the oval niche can cause significant inner ear trauma through vibrations. On the other hand, CO_2 laser stapedotomy can create a perforation in the stapes footplate, regardless of its thickness or degree of fixation, without mechanical trauma to the inner ear.

The SurgiTouch™ settings are the same as laser stapedotomy. After removal of the superstructure, the otosclerotic foci obliterating the oval window niche are extensively and evenly ablated by applying laser irradiation. Vaporisation continues until the margins of the oval window can be identified precisely (Figs. 9A,B). The energy levels are lowered as the margins of the oval window are approached, in order to avoid an accidental breach of the inner ear. The ablation of thick bone yields a considerable amount of by-products in the form of carbonisation and crystallisation. These products create a barrier between the bone and the laser energy. They absorb the energy themselves, and effectively stop any further bone ablation. Furthermore, as these products heat up, they impart their heat to the surrounding tissue by conduction. Therefore, the collateral thermal effect increases while the effect on the target area diminishes. Thus, accumulation of these products is undesirable, and they should be removed periodically using cold instruments,



A.

B.

Fig. 9. Vaporisation of obliterative otosclerotic footplate. A. Otosclerotic foci are evenly vaporised with the laser. B. Debri and charred tissue is periodically removed.

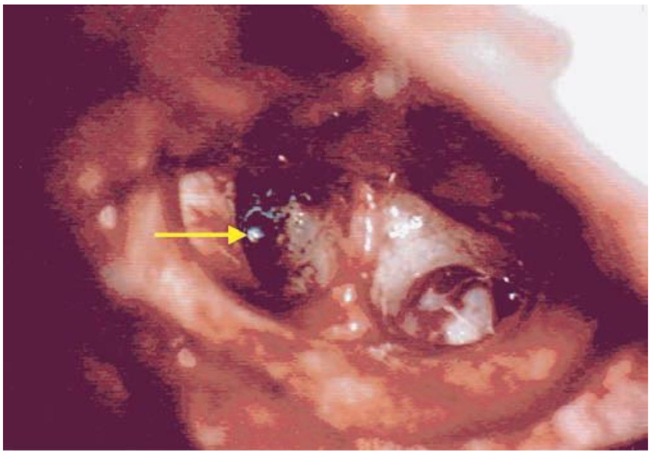


Fig. 10. Opening made in obliterative footplate.

such as a curved needle or a suction device. The vestibule is opened at the centre of the oval niche (Fig. 10), and the perforation is then concentrically enlarged to the required diameter by additional single applications. The prosthesis is inserted in the usual way.

9. The narrow niche of the oval window

A wide range of normal anatomical variations in the width of the oval niche is not uncommon. Moreover, a niche may also be rendered too narrow by an overhanging bony facial canal or bare facial nerve in the tympanic segment, or by a prominent and overhanging promontory projecting into the oval niche. In such cases, additional surgical measures are required for successful stapedotomy.

10. Overhanging facial nerve

This anatomical variant causes major problems in its surgical management. Bone covering the facial nerve can be carefully and tangentially ablated by the CO_2 laser beam without a scanner using low powers (1–1.5 W) and a short pulse duration of 50 msec.

The facial nerve should not be completely denuded from its bony covering. A bare nerve tends to prolapse into the oval window, reducing its width. A bare nerve is also liable to damage by laser radiation. Partial removal of the bone is sometimes adequate for gaining sufficient access to create a perforation in the footplate.

If the facial canal completely obstructs the oval niche and no appreciable widening can be achieved by removing the often very thin bone, or if the tympanic part of the facial nerve has no bony covering, laser surgery should be abandoned in favour of other types of conventional stapedotomy with cold instruments. A suitable mirror to deflect the CO_2 laser beam may also be useful here, and may enable the surgeon to perforate a footplate not directly accessible to the laser beam.

11. Projecting promontory

A projecting promontory often narrows the niche. Careful tangential ablation of the overhanging bone helps define the footplate for accurate perforation. Low powers of 1-2 W and a short pulse duration of 50 msec are also used here. Physiological saline or a gelatin sponge are used to protect the footplate from inadvertent perforation, and thus from premature opening of the vestibulum with leakage of perilymph.

While inserting the usually somewhat longer prosthesis, care must be taken to ensure that the wire does not come into contact with the projecting facial nerve or other structures in the oval niche. This is an absolute prerequisite for good sound conduction. Finally, the oval window niche is sealed with connective tissue.

12. Overhanging promontory

Narrowing of the niche to the oval window by an overhanging promontory wall projecting into the oval niche usually presents a less onerous surgical problem. Taking the above-mentioned precautions (covering the footplate with saline or a damp gelatin sponge), powers of 1-2 W and a short pulse duration of 50 msec can be used to ablate the overhanging bone tangentially, and thus to improve visibility in the oval niche. The surgical technique required will determine whether it is better to perform this measure before or after removing the stapes suprastructure.

While ablating the overhanging promontory, care must be taken not to open the scala tympani of the cochlea and cause inner ear damage. However, the risk of inner ear damage by inadvertently opening the scalae is far less with the CO_2 laser beam than with conventional tools, *e.g.*, a diamond drill, due to its complete absorption in the perilymph and its low penetration depth of 0.01 mm. Thus, the inner ear structures are well protected from direct CO_2 laser irradiation and are safe from damage over a relatively wide energy range.

13. Otosclerosis in the vicinity of the round window

The reported incidence of round window occlusion by otosclerotic foci varies widely in the literature, ranging from less than 1% (Plester, 1986) to 50% (Fleischer, 1957). This pathology is nearly always accompanied by severe sensorineural hearing loss. We have not observed this phenomenon in either its isolated form or combined with stapes fixation in any of our patients.

Laser ablation is basically conceivable even if the round niche is completely obliterated by otosclerotic foci. However, it must be borne in mind that the round window membrane is very thin and its anatomical position varies widely in relation to the promontory. If the membrane is inadvertently opened, the round window must be sealed immediately with connective tissue or middle ear mucosa.

14. Surgical procedure for an inaccessible footplate

If the footplate is inaccessible due, for example, to an abnormal course of the facial nerve or to a vascular anomaly, fenestration of the promontory according to Plester may be necessary for restoring the sound-conducting apparatus (Plester *et al.*, 1989). The surgical technique corresponds to the conventional procedure except that perforation is performed with the CO_2 laser. The laser parameters required are those used for footplate perforation.

15. Floating footplate

When a stapes is partially fixed, manipulation by conventional stapedotomy often leads to accidental mobilisation of the stapes and results in a so-called 'floating footplate'. Surgery is then hazardous since the footplate can no longer be perforated with conventional instruments in many such cases, and the operation is either abandoned or a total stapedectomy carried out. The CO_2 laser is most useful in such cases. It creates a non-contact perforation of predetermined diameter even in a floating footplate, without the associated trauma of a conventional cold instrument. A platinum Teflon piston can then be inserted in the usual way.

It is worth emphasising that one potential benefit of laser stapedotomy over conventional stapedotomy is that the incidence of floating footplate is extremely low in laser stapedotomy. In our experience, it is as low as 0.5%. Where floating did occur, unlike conventional stapedotomy, stapedectomy was not required in any of the cases. This in itself must be a strong argument in favour of laser stapedotomy as opposed to conventional techniques.

16. Laser versus conventional surgery

Before considering any new techniques, comparison with established techniques is appropriate. However, this comparison is not suitable for all series because cohorts vary considerably from report to report. In older studies, the air-bone gap for 0.5, 1, and 2 kHz was averaged, while in recent studies, the frequency of 3 or 4 kHz was also included. A search of the literature covering major publications produced the data presented in Table 2.

Table 2.

	Laser surgery	*Conventional surgery*
Closure of the air-bone gap to within 10 dB	67-99%[1]	40-96%[2]
Closure of the air-bone gap to within 20 dB	85-99%[1]	68-99%[2]

[1]McGee, 1983; Lesinski, 1989; Horn *et al.*, 1990; Lesinski, 1990b; Vernick, 1996; Beatty *et al.*, 1997; Shabana *et al.*, 1999; Buchman *et al.*, 2000

[2]Moon *et al.*, 1984; Levy *et al.*, 1990; Hodgson and Wilson, 1991; Rauch and Bartley 1992; Backous *et al.*, 1993; Strunk and Quinn, 1993; Fisch, 1994; Somers *et al.*, 1994; Glasscock, *et al.,* 1995; Persson *et al.*, 1997; Ramsey *et al.*, 1997; Shea *et al.,* 1999; Häusler, 2000

16.1. Our data on laser stapedotomy

Between 1990 and 2000, 281 patients with otosclerosis underwent CO_2 laser stapedotomy. The patients had a mean age of 43.3 (10–80) years, with mean age of 43.5 years for females and 44.2 years for males. The sex distribution showed a female:male ratio of 1.7:1 (177 females and 104 males). The procedure was carried out on the right side in 156 and on the left side in 125 patients, and bilateral operations were carried out in 25 cases.

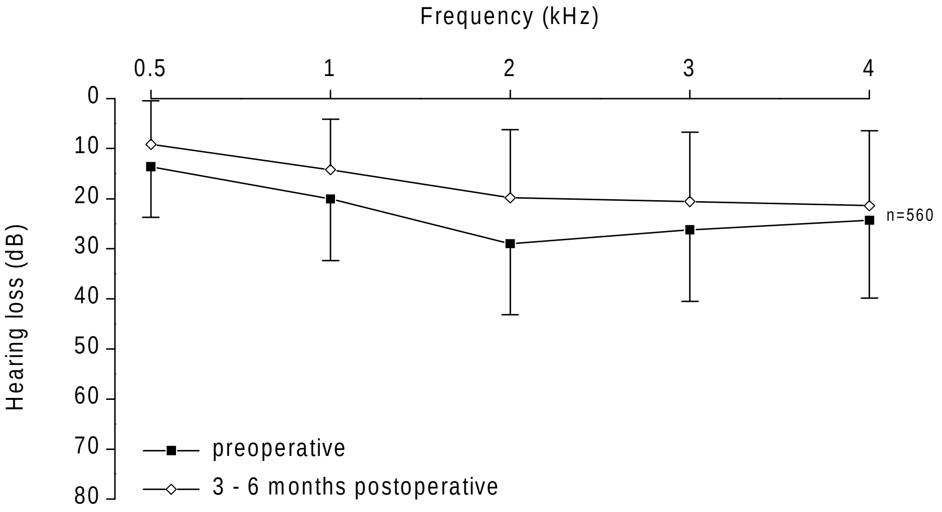


Fig. 11. Mean pre- and postoperative bone conduction thresholds.

16.2. Sensorineural hearing loss

Figure 11 shows the mean bone conduction threshold at 0.5, 1, 2, 3, and 4 kHz prior to CO_2 laser stapedotomy and at three to six months postoperatively. Preoperatively, the mean sensorineural hearing loss was 14 dB HL at 0.5 kHz and 28 dB HL at 2 kHz (Carhart phenomenon). Three to six months postoperatively, the mean bone conduction threshold showed an improvement of about 3 dB at 0.5 and 4 kHz and of about 9 dB at 2 kHz, and a statistically significant improvement of the bone conduction threshold (Wilcoxon test, $p < 0.01$).

At 4 kHz, two patients showed a loss of 15 dB and a further two, of 20 dB (2.5%, $n = 4/160$ patients) in postoperative bone conduction threshold. None of the patients showed a loss greater than 20 dB. In the speech frequency (mean 0.5, 1, 2, 3 kHz), no patient demonstrated significant sensorineural hearing loss (10 dB or greater).

16.3. Air-bone gap

Figure 12 compares the mean pre- and postoperative air-bone gap in 160 patients with a follow-up of more than one year (one to nine years). The air-bone gap improved continuously within the

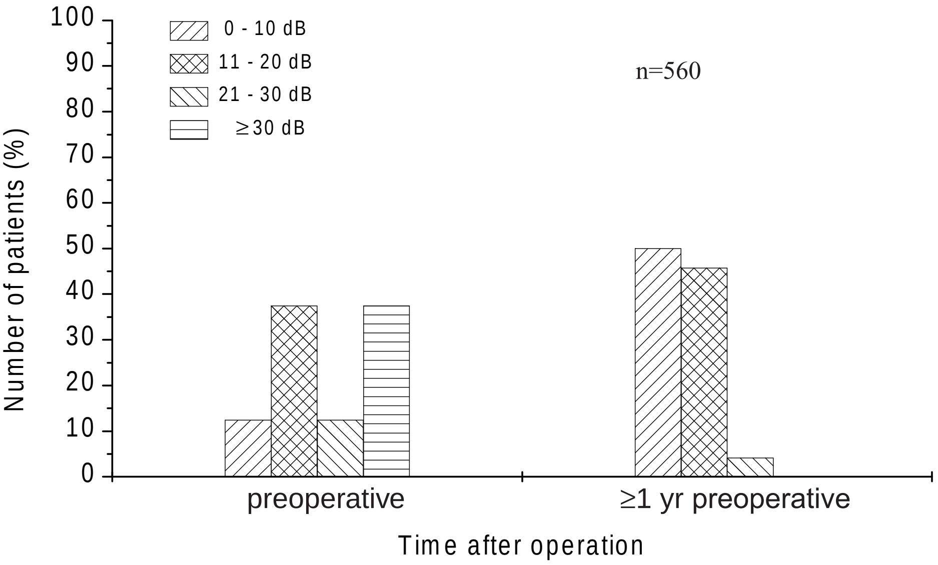


Fig. 12. Mean pre- and postoperative air-bone gap.

Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery, edited by V. Oswal, et al., Kugler Publications, 2014. ProQuest Ebook Central,

first year. After one year, 97% of the patients had maintained closure of the air-bone gap within 20 dB (0-10 dB in 74%, 11-20 dB in 23%). None of the patients developed poor hearing (air-bone gap >30 dB).

The mean speech-recognition threshold by air conduction (hearing level at a discrimination level of 50%) showed an improvement from 48 dB HL preoperatively to 23 dB HL postoperatively, with a follow-up period of more than one year. The one-year results can be regarded as definitive, since they showed no further deterioration (Fisch and Rüedi, 1968; Fisch, 1979; Committee on Hearing and Equilibrium of the AAOHNS, 1995).

17. Patient risks and benefits

The usual complications in any stapes surgery consist of sensorineural hearing loss, vertigo, accidental mobilisation of the foot-plate (floating footplate), and accidental fracturing of a thin footplate, etc. The data in the literature clearly document that the incidence and severity of postoperative complications after CO_2 laser stapedotomy are lower than after conventional interventions (Rauch and Bartley, 1992; Lesinski and Newrock, 1993; Shabana *et al.*, 1999; Buchman *et al.*, 2000). Our results support these data (Jovanovic *et al.*, 1995g; 1996a). The following is a summary of the analysis of 281 procedures.

- *Intraoperative complications:* none.
- *Revision surgery:* 22 of 281 patients (7.8%) required revision surgery, the first at two days postoperatively and the last after 5.5 years (median, 17 days; mean, 2.2 years).
- *Postoperative sensorineural hearing loss:* three of 281 patients (1%) had significant postoperative sensorineural hearing loss (permanent threshold shift: 1020- dB), two in the high frequencies, and one in all frequencies. In the first two cases, the loss was of unknown aetiology. One patient (0.3%) had severe sensorineural hearing loss (permanent threshold shift: 4050- dB) in all frequencies.
- *Perilymph fistula:* a perilymph fistula was noted due to a short prosthesis. Following revision surgery, no improvement in sensorineural hearing loss was seen.
- *Granuloma:* a granuloma was noted in one patient.
- *Temporary tinnitus:* six patients suffered from temporary tinnitus, which persisted for up to six weeks postoperatively.
- *Conductive loss related to prosthesis:* as in conventional surgery, some cases showed a hearing loss due to displacement of the prosthesis, a short prosthesis, loose wire, or erosion of the incus. Adjusting or replacing the prosthesis improved hearing.
- *Postoperative fibrosis:* in one patient, the incus was immobile due to thick mucosal adhesions. These were vaporised with the laser and mobility was restored, resulting in improvement in conductive loss.
- *Inadequate stapedotomy:* in two cases, stapedotomy was too small, and compromised the mobility of the prosthesis. Early revision within a period of two weeks with enlargement of the perforation improved the hearing.
- *Vestibular symptoms:* eight patients had to undergo revision surgery within the first postoperative week due to persistent vestibular symptoms. At operation, the prosthesis was found to be too long and was replaced with a shorter one, with immediate improvement of dizziness. In the first postoperative week, ten patients reported mild vertigo with queasiness when standing up or on rapid head movements. Four weeks postoperatively, none of these patients had any residual symptoms of vestibular irritation. None of the 15 patients operated on under local anesthesia complained of vertigo during and/or immediately following vaporisation of the stapes footplate with the CO_2 laser.
- *Facial nerve dysfunction:* one patient who had a dehiscent facial nerve canal developed delayed facial weakness (two weeks postoperatively), which improved completely within one week.
- *Chorda tympani function:* six patients (2%) had transient taste disturbance.
- *Tympanic membrane perforation:* none.

18. Revision surgery

Successful restoration of hearing in revision stapedotomy consists of precise identification and cor rection of a single or multiple factors, without damaging the integrity of the inner ear.

In revision stapes surgery, conventional surgical procedures often produce poor results. Several workers (Crabtree *et al.*, 1980; Lippy, 1980; Sheehy *et al.*, 1981; Glasscock, 1987) have shown that a successful closure of the air-bone gap of less than 10 dB could only be achieved in less than half the patients. Worse still, conventional revision operations resulted in poor overall hearing in 8-33% of all revision patients.

There is also the strong possibility of iatrogenic inner-ear trauma during conventional revision procedures. The incidence of significant postoperative sensorineural hearing loss after conventional revision surgery is between 3 and 20%. The poor results of conventional revision surgery are probably due to excessive manipulation of the prosthesis and over-zealous removal of fibrous tissue from the oval window niche, which appear innocuous, but have the potential for causing permanent inner ear damage.

Histopathological studies carried out by several workers on the petrous bone of stapedectomised patients showed dense adhesions between the prosthesis and the neomembrane (Hohmann, 1962; Linthicum, 1971). Surgical manipulation of these adhesions during revision surgery may lead to rupture of the utricle and saccule with resultant vertigo and labyrinthine damage.

The use of lasers for revision surgery offers a distinct advantage over the conventional method.

The complication rate is low and the statistically significant, improved success rate is independent of the laser system used (McGee *et al.*, 1983; Lesinski, 1989; Gherini *et al.*, 1990; Lesinski and Newrock, 1993; Horn *et al.*, 1994; Silverstein *et al.*, 1996; Haberkamp *et al.*, 1996; Wiet *et al.*, 1997, etc.). Measured as closure of the air-bone gap of 20 dB or less, the rate of success with laser surgery ranges from 70-92%, compared to 49-85% with the conventional technique.

While exploring the middle ear for failed stapedotomy, the surgeon is often faced with a difficult task. In order to ascertain the precise cause of failure, it is necessary to 'explore' the middle ear structures by probing and removing the fibrous bands covering the oval window. The functional integrity of the prosthesis requires manipulation. Some surgeons may not wish to probe too widely in order to avoid damage to the inner ear, and therefore cannot carry out corrective measures, while the more inquisitive ones may unwittingly cause the hearing to become worse by excessive manipulation.

If the old prosthesis can be extracted without excessive manipulation, it is replaced with a shorter one. In a significant number of cases, the cause of migration of the prosthesis may be the cause of failure. Removal and replacement of the prosthesis with a shorter one may result in improvement. It is not surprising that the reported success rate for revision stapedectomy operations is only 30-50%.

18.1. Revision CO_2 laser surgery for failed cases

Following elevation of the tympano-meatal flap, the middle ear is inspected first. The integrity and mobility of the malleus and incus are checked by palpation with a Rosen needle.

Using experimentally determined, effective and safe laser energy parameters (Table 3), the adhesions are first vaporised with the CO_2 laser. A beam diameter of 180 µm and a low power of 1-2 W at a pulse duration of 0.05 seconds is adequate for this purpose. If the SurgiTouch™ scanner system is used, a power setting of 4-8 W at a pulse duration of 0.03-0.05 seconds, and variable scanner diameters (0.5-0.7 mm) are sufficient for soft tissue ablation. With these parameters, the prosthesis is exposed and freed by vaporisation of the surrounding soft tissue. It may be necessary to widen the perforation by the application of single strikes of laser energy to the existing oval window perforation (power: 6 W; pulse duration: 0.05 seconds).

18.2. Laser interaction with the prosthesis

In the case of a wire/connective-tissue prosthesis (*e.g.*, one made of platinum), even direct lasering of the prosthesis is harmless. However, direct strikes on a prosthesis with a piston made of Teflon (*e.g.*, a platinum Teflon piston) must be avoided, since the Teflon cannot withstand the high temperatures (>300°C) of the laser irradiation. The surface swells up like a mushroom, without disintegration or ignition.

Table 3. Effective laser energy parameters for *revision* stapes surgery (AcuPulse TM CO_2 SurgiTouch TM Laser with the micromanipulator Acuspot 712, Lumenis Inc)

Anatomical structure	Real power (W)	Power density (W/cm²)	Pulse duration (s)	Mode	Diameter of irradiation (mm)	Number of pulses	Diameter of perforation (mm)
Soft tissue	1-2	4000-8000	0.05	cw	0.18		
Bony stapes footplate	6	24000	0.05	cw	0.18	6 - 12	0.5 - 0.7
	or 20-22*	80000-88000	0.03 or 0.05	cw	ca. 0.5 , 0.6 or 0.7	1	0.5 - 0.7
Connective-tissue neomembrane	1-2	4000-8000	0.05	cw	0.18	6 - 12	0.5 - 0.7
	or 4-8*	16000 - 32000	0.03, 004, 0.05	cw	ca. 0.5 , 0.6 or 0.7	1	0.5 - 0.7

Focal length: f = 250 mm; focal size: 0.18 mm (Acuspot 712®)
* Application of laser irradiation with rotating mirrors (SurgiTouch®)
Specified powers correspond to real powers at the end of the application system. Use of rotating application systems at the stapes footplate may require perforation enlargement by additional individual applications without a rotating laser beam (power: 6 W, pulse duration: 0.05 sec)

18.3. Removal of the prosthesis

The prosthesis is freed from any adhesions by vaporising them with the laser. The soft tissue covering the oval window is then vaporised until its margins are clearly visible. When all adhesions are completely severed, the prosthesis is freed from the incus with a 2-mm long 90° hook, and removed. While performing the procedure under local anaesthesia, if the patient experiences any vertigo, the manipulation is aborted. The distal end of the prosthesis is checked again, and any residual adhesions severed.

18.4. Laser stapedotomy for revision surgery

The aiming beam is placed in the centre of the well-defined oval window, and a 0.5-0.7-mm stapedotomy is carried out with either the single-shot or multiple-shot method, as in primary cases, until the perilymph is clearly visible. If bone requires vaporisation, with a beam diameter of 180 µm, the power is increased to up to 6 W.

18.5. Renewal of the prosthesis

The length of the prosthesis is determined precisely (usually 4.5-4.75 mm) by measuring the distance between the vestibule and the lower surface of the incus and adding 0.2 mm. To reduce the risk of renewed prosthesis migration, the prosthesis should project 0.1-0.2 mm into the stapedotomy opening. The platinum Teflon piston is then inserted into the perforation and, if the incus is intact, fixed to the incus neck. In the case of a completely eroded incus, malleo-vestibulopexy is performed to restore ossicular continuity. Finally, the oval window niche is sealed with connective tissue or a blood clot.

19. Discussion

19.1. Surgical skill for stapes surgery

Stapes surgery involves set steps for the procedure and does not call for much ingenuity on the part of the surgeon. Nevertheless, the minutia and fineness of the procedure do require a very high degree of skill, and stapes surgery can be rated as the most delicate of all the surgical procedures an otolaryngologist is called upon to perform. The skill is taught at the senior resident stage when the trainee has almost completed his or her training. Thus, every trained surgeon can perform stapedotomy. But can every surgeon acquire a high enough level of skill to start performing stapes surgery? It is a fact of life that skill level is a variable commodity, although the steps of the operation remain uniform.

19.2. Refinement of the instrumentation

If skill level cannot be rationalised, is there a need to devise alternative methods that demand a lower level of skill and are therefore more readily available? Does laser stapes surgery meet this requirement? Or is it a panacea, the fashion of the day, or the fancy of a bunch of enthusiasts? It is worth addressing these questions so that those who have not used the laser for stapes surgery yet, can make a rational decision.

Mechanical instruments such as a drill or a perforator involve skilled manipulation which can only be provided by years of apprenticeship and practice. In experienced hands, conventional stapedotomy can result in a very successful outcome. The various cleverly devised methods of perforating the footplate and re-establishing continuity are well-tried and time-honoured methods. Even then, there is no getting away from the fact that vibrations from these instruments may impart a certain degree of trauma to the inner ear. It is not easy to create a precise, round perforation. In fact, in some situations, mechanical instruments can prove hazardous. For example, a partially fixed stapes is often accidentally mobilised by manipulations (floating footplate), and a thin footplate is not infrequently fractured. In obliterative otosclerosis, perforation of a thick obliterating footplate with the drill can cause significant inner ear trauma due to vibrations.

On the other hand, laser stapedotomy, with the non-contact method, can create a circular perforation regardless of the thickness of the footplate. The non-contact technique minimises trauma to the inner ear. It is of course necessary to use the correct laser wavelength and experimentally established parameters.

The results of previous studies support the use of both visible (argon and KTP) and invisible, far infrared (CO_2) laser systems for primary otosclerosis surgery (Perkins, 1980; DiBartolomeo and Ellis, 1980; McGee, 1983; Palva, 1987; Silverstein *et al.*, 1989; Lesinski, 1989; 1990a,b; Bartels, 1990; Horn *et al.*, 1990; Hodgson and Wilson, 1991; Rauch and Bartley, 1992; Lesinski and Newrock, 1993; Molony, 1993; Causse *et al.*, 1993; Gherini *et al.*, 1993; Vernick, 1996; Beatty *et al.*, 1997; Antonelli *et al.*, 1998; Shabana *et al.*, 1999; Buchman *et al.*, 2000).

We have used the CO_2 laser for stapedotomy. The technical advances in laser technology permit one-shot stapedotomy in most cases where the footplate is reasonably thick. Other workers have used argon and KTP lasers.

In revision stapedotomy, the CO_2 laser provides the ear surgeon with three important advantages compared to the conventional technique:

- improved diagnostic precision;
- the possibility of improving stability of the new prosthesis in the centre of the oval niche; and
- reduction of inner ear trauma.

Our results so far (Jovanovic *et al.*, 1997a) suggest an improvement in postoperative hearing results and elimination of a significant hearing loss after revision stapedotomy. The CO_2 laser enables the ear surgeon to review failed cases, assess the aetiology of failure with a greater degree of accuracy, and undertake corrective surgery for improving middle ear function.

20. Summary

The role of the CO_2 laser in stapes surgery can be summarised as follows:

- The main advantage of the CO_2 laser surgery lies in minimising the trauma it causes to the inner ear at the first operative intervention. The laser is used to vaporise the tendon, open the incudo-stapedial joint, and vaporise the crura. In the final stage of surgery, it is used to make
- a precise, perfectly circular perforation in the footplate.
- One-shot stapedotomy achieves an adequately large (0.50.7- mm in diameter), circular footplate perforation, without appreciable thermal damage to the surrounding area. It represents a considerable advance in CO_2 laser stapedotomy.
- The postoperative air-bone gap closure in primary laser stapedotomy is comparable to that following conventional surgery.
- The central placement of the prosthesis reduces the incidence of migration, which is by far the most frequent cause for the recurrence of conductive hearing loss after stapedotomy or stapedectomy.
- In the case of a partially fixed footplate, the incidence of mobilisation is almost non-existent during laser procedures.
- In obliterative otosclerosis, the laser allows the removal of bone, layer by layer, until the margins of the oval window are clearly defined.
- In revision surgery, non-touch vaporisation of the fibrous tissue of the oval window niche and that surrounding the prosthesis allows accurate diagnosis of the conductive loss. The prosthesis can be removed without rupture of the utricle and saccule. A central perforation can be created in the neomembrane, and a new prosthesis placed in the centre of the oval window niche to minimise the risk of migration. In our experience, some revision operations can only be performed safely by laser. For example, dense mucosal adhesions, which obscured any landmarks, were vaporised with the non-touch technique until all structures were clearly demarcated.
- In our experience of almost 300 stapedotomies and more than 50 cases of revision surgery with the CO_2 laser, there were no intraoperative complications. In primary surgery, three patients (1%) postoperatively showed significant sensorineural hearing loss, and one patient (0.3%) severe sensorineural hearing loss, which was probably caused by a granuloma and showed no improvement following revision surgery. During revision surgery, one patient (1.8%) developed severe sensorineural hearing loss. No late cases of deafness were observed. The mean sensorineural hearing losses before and after CO_2 laser stapedotomy clearly show that there was no appreciable dysfunction of inner ear function. A vestibular dysfunction occurred in only eight cases due to the length of the prosthesis. These results are similar to the results of Lesinski and Newrock (1993) and Lesinski and Stein (1992) in over 200 CO_2 laser stapedotomies and stapedectomy revisions.
- A clean non-touch technique demands far less surgical skill from the surgeon.

The modern CO_2 laser is well suited to application in stapes surgery. With strict adherence to the parameters, it contributes to the optimisation of this high-precision intervention and shows promise in reducing the incidence of inner ear damage. Its performance in obliterative otosclerosis and in revision stapedotomy is superior to the conventional surgical technique.

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MCQ – 36. CO_2 laser in stapes surgery

1. The role of lasers in stapes surgery is
    a. To shorten the operative time
    b. To minimise potential damage to the inner ear
    c. To ensure that the facial nerve is not damaged
    d. To achieve nearly bloodless surgery
    e. To minimise manipulation of ossicular chain

2. Theoretically, inner ear damage due to laser energy can occur due to
    a. Transmission of heat to stria vascularis during CO_2 laser stapes surgery
    b. Fibre delivery of KTP laser stapes surgery
    c. Cold surgery instrumentation required during KTP laser stapes surgery
    d. The pressure waves resulting from Er:YAG laser stapes surgery
    e. Higher sound levels generated during Er:YAG laser stapes surgery

3. Absorption of laser energy at the footplate is higher
    a. When CO_2 laser is used
    b. When fibre delivered Argon laser is used in near contact mode
    c. Er:YSGG wavelength ($\lambda = 2.78$ μm) is used
    d. When Ho:YAG pulsed laser is used
    e. When excimer laser at 300nm is used

4. CO_2 laser is used to
    a. Vaporise bony posterior canal wall until most of the stapedius tendon is seen
    b. Vaporise the stapedeus tendon
    c. To vaporise the posterior crus
    d. Vaporise the bone of the footplate to create a fenestra of 0.5 – 0.7 mm in diameter
    e. All of the above

5. During CO_2 laser surgery, inner ear damage is greater
    a. When the laser is used in continuous mode
    b. When the laser is used in super pulse (SP) mode
    c. When high precision micromanipulator, delivering very high energy over a small surface is used
    d. When high power density is delivered on the footplate, using scanner system
    e. All of the above

6. During CO_2 laser surgery, inner ear damage is almost non-existent because
    a. The perilymph has a high absorption coefficient for the CO_2 laser wavelength
    b. The CO_2 laser energy is maximally absorbed by the bone of the footplate without causing any charring.
    c. Scanning system creates several micro-perforations in a circular fashion at a *high* energy but short exposure time thus minimising deep spread of thermal energy
    d. Scanning system creates many micro-perforations in a circular fashion at a *low* energy due to short exposure time thus minimising deep spread of thermal energy
    e. Scanning system can be set to create a *single* large perforation – the so called *single shot* fenestra - measuring between 0.5 -0.7 mm in diameter, at a low energy due to short exposure time thus minimising deep spread of thermal energy

7. If CO$_2$ scanner system is not available
   a. Laser stapes surgery cannot be done
   b. CO$_2$ laser energy should be applied with micromanipulator at high energy setting to create a perforation with a single shot to avoid heat transmission to the inner ear
   c. Several juxtapositioned single shots at a low power, small beam diameter and short pulse duration applied in a circular fashion
   d. The energy should be applied at a low power but large beam diameter and repeated at the same spot until a desired diameter fenestra is achieved

8. In obliterative otosclerosis
   a. CO$_2$ laser should not be used due to loss of landmark of the footplate
   b. CO$_2$ laser should not be used due to excessive char production
   c. CO$_2$ laser can be used to vaporise the thick bone until the outline of the footplate is visible
   d. Charring due to CO$_2$ laser strikes protects the inner ear from excessive heat
   e. Charring due to CO$_2$ laser strikes increases the chances of thermal trauma to the inner ear

9. In a facial overhang
   a. CO$_2$ laser usage is not possible if the exposed area of the footplate is extremely small
   b. CO$_2$ laser usage is possible by removing the bony overhang until the facial nerve is denuded. It is then protected with gelfoam and the laser used to create a fenestra
   c. CO$_2$ laser can be used to remove only the bony overhang to achieve sufficient exposure of the surgical site for creating the fenestra
   d. Care must be taken that the prosthesis does not press on the exposed facial nerve
   e. Fibre-delivered laser is more suitable

10. The floating footplate
    a. Is a contra indication to undertake laser stapes surgery
    b. Requires stapedectomy using cold instrumentation
    c. CO$_2$ laser is ideal since it is a non-touch technique
    d. The pressure wave from the CO$_2$ laser is easily transmissible and will result in inner ear damage
    e. KTP fibre-delivered laser is more suitable since it has a tactile feedback and therefore more accurate control

11. Complications solely due to the use of the CO$_2$ laser relate to
    a. Increased incidence of postoperative sensory neural hearing loss
    b. Floating footplate
    c. Facial nerve paralysis
    d. Increased incidence of postoperative dizziness
    e. None of the above

Chapter 37

Laser cartilaginous Eustachian tuboplasty

D.S. Poe

1. Introduction

The function of the Eustachian tube is to regulate the air pressure in the middle ear and mastoid air cell system, to clear normal secretions from the middle ear, and to prevent the reflux of secretions or sound from the nasopharynx (Bluestone and Doyle, 1985; Poe *et al.*, 2000). Failure of tubal function can result from mucosal inflammation and disease, or, from impairment of the tensor veli palatini muscle (TVPM) or levator veli palatini muscle (LVPM). Mucosal inflammation and oedema is the most frequent aetiological factor, resulting from inflammatory disease, infection, allergy, or extraoesophageal gastric reflux. The oedematous mucosa at the entrance of the tube leads to a reduction in the diameter of the lumen and insufficient dilation.

Primary muscular dysfunction of the TVPM or LVPM results in hypo- or, hyper-activity or even incoordination between the two. (Poe *et al.*, 2000) Mucosal inflammatory disease as well as muscular (dynamic) dysfunction leads to functional obstruction of the Eustachian tube (Cantekin *et al.*, 1980). Complete anatomical obstruction is quite rare, but when present, it is nearly always secondary to neoplasms.

Several tuboplasty techniques have been described (Jansen, 1985; Charachon *et al.*, 1986; Zini, 1988). These surgical procedures were undertaken in the bony, and not the cartilaginous, portion of the Eustachian tube. In most cases, however, chronic Eustachian tube dilatory dysfunction (Bluestone and Klein, 1995; Tos, 1991) is due to pathology in the cartilaginous portion and thus procedures on the bony portion were not successful in resolving tubal obstructive dysfunction.

2. Surgical anatomy of the Eustachian tube

The Eustachian tube is formed by the superior (lateral) bony one-third and the inferior (medial), cartilaginous two-thirds. The bony portion is predominantly a funnel-shaped extension of the middle ear. It tapers down to the isthmus, which is the narrowest part of the tube. It is lined with a thin layer of cuboidal respiratory epithelium and is normally patent. The cartilaginous portion is composed of the cartilaginous skeleton, associated with a complex arrangement of peritubal muscles that are capable of a wide range of dynamic movements. The lumen of the cartilaginous portion is lined by a pseudostratified respiratory epithelium. The cartilaginous portion is not patent in the normal resting state. However, the tube opens when the medial cartilaginous lamina within the torus tubaris is rotated medially and pushed upwards by contraction of the LVPM during swallowing or yawning. The TVPM is the main tubal dilator (Cantekin *et al.*, 1979; Honjo *et al.*, 1980); its contraction brings forward the lateral lamina of the Eustachian tube, inducing lateral shifting of the anterolateral wall of the lumen.

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3. Signs and symptoms of Eustachian tube dysfunction

Chronic dilatory dysfunction of the Eustachian tube results in a reduction of pressure in the middle ear as gas exchange within the middle ear causes a net loss by absorption of the air into the venous circulation. Patients present with various complaints, including hearing loss, tinnitus, aural pressure, otalgia and difficulty in clearing their ears during flights or diving into water. A careful history should always be taken to identify risk factors such as allergic disease, laryngopharyngeal reflux, nasosinus disease, immune-deficiency or compromise, connective tissue and granulomatous disorders. Their medical management may offer the possibility for a successful outcome. A strong family history of middle ear disease may suggest genetic factors in the aetiology. Examination of the ear by otoscopy or otomicroscopy may reveal retraction or atelectasis of the tympanic membrane and middle ear effusion. Tuning fork testing demonstrates conductive hearing loss. More advanced cases may show fixed retraction pockets, tympanosclerosis, tympanic membrane thinning, perforation, or cholesteatoma. (Bluestone *et al.*, 1972; 1974; Tos, 1991; Sando *et al.*, 1994; Bluestone and Klein, 1995; Sadé and Amos, 1997).

4. Investigations and diagnosis

A meticulous search will elucidate the aetiology of Eustachian tube disorders that can be suitably and effective managed with medical therapy. Evaluation of the Eustachian tube includes a complete head and neck examination and endoscopic study of the nasal cavity, nasopharynx, larynx and the Eustachian tube itself. Additionally, audiometry and tympanometry are crucial in quantifying the effects of tubal dysfunction on the ear. In particular, these examinations estimate the mobility of the LVPM and the TVPM; assess the aperture of the nasopharyngeal orifice of the Eustachian tube, and its ventilatory capability in steady state. Failure of medical therapy and continuing alteration of one or more of these parameters is an indication for surgical management.

5. Indications for tuboplasty

Efforts should be maximised to identify underlying causes for Eustachian tube disorders, since; the majority will improve with appropriate medical therapy. Refractory cases, with persistent inflammation, oedema and failure to ventilate the middle ear adequately with tympanostomy tubes, may be considered for tubal surgery. Medical therapy will not correct the primary muscular disorders including weakness or incoordination between the LVPM and TVPM. In such cases, intratubal surgery may be considered.

6. Laser tuboplasty

A technique of endoscopic transnasal, laser-assisted, cartilaginous Eustachian tube surgery, known as laser Eustachian tuboplasty (LETP) was developed for chronic obstructive Eustachian tube dysfunction (Kujawski, 2000; 2001). The goal of laser tuboplasty is to remove the oedematous tissue in the posterior tubal wall by laser vaporisation, with minimal thermal effects on the underlying tissue. Reduction of the oedematous mucosa restores the patency of the lumen of the tube, and thus, enables ventilation of the middle ear during TVPM contraction. If muscular dysfunction is also involved in the tubal dysfunction, a portion of the medial cartilaginous lamina is debulked in order to weaken the elasticity of the cartilaginous skeleton, so that the contraction of the LVPM and TVPM is more effective in opening the lumen.

7. Choice of laser

Laser Eustachian tuboplasty has been accomplished using the CO_2, diode and KTP lasers. The diode laser offers some significant advantages over the CO_2 laser. Since the diode laser has much deeper penetration, the energy setting must be very precise. It is also mandatory that the energy be used in the pulsed mode rather than the continuous mode, in order to avoid excessive thermal damage, with potential chondronecrosis. The healing process is similar with both the CO_2 and diode lasers.

The waveguide delivery of the CO_2 laser results in some loss of power with changes in curvature. Recent improvement in waveguide technology has reduced the loss of power with improved transmission capabilities.

The small-diameter optical fibre for diode delivery allows alteration of the axis of delivery of the distal end without modifying the beam parameters. Unlike the CO_2 laser, the diode laser provides better haemostatic control. The overall size of the diode instrumentation is significantly reduced, thus facilitating its use in younger patients.

The diode laser operates in a wavelength (810 or 980 nm) in which water or haemoglobin absorption is poor. Consequently, the diode laser must be used in contact mode for its thermal properties and should not be used as a free beam in which the laser effects can occur as much as a centimetre deep.

The KTP laser emits in a visible part of the electromagnetic spectrum, 532 nm. It is fibre-transmissible. A 200-micron diameter fibre is contained within an otologic surgical hand piece consisting of a malleable metal sheath that can be easily conformed to pass from the mouth superiorly into the nasopharynx. Transoral passage of instruments permits more freedom of movement compared to the transnasal route. A solid-state diode-pumped KTP laser with maximum output of 2.5 W is adequate for mucosal vaporisation, although it is less efficient than the more powerful diode or CO_2 lasers. Absorption of KTP wavelength is maximal by pigmented tissue, such as a char from previous laser burns or haemoglobin in a blood vessel. Ablation of white cartilage is possible with KTP. However, it initially requires near contact strikes on the tissue, which result in maximum power density to form charring. It causes more charring than the CO_2 or diode lasers and is less effective for haemostasis. In contrast to free beam diode energy, the maximum KTP laser effects on pigmented tissue are on the surface of the tissue, the deeper penetration is minimal. The advantages of the solid state KTP laser are lower cost, small size of the machine and ready availability of the laser since it is commonly used as ophthalmologic laser.

8. Anaesthesia

This ambulatory procedure is carried out under general anaesthesia.

9. Preoperative preparation

The entrance to the lumen is initially packed with adrenaline solution (1:100:000), which is left *in situ* for ten minutes. The mucosa of the posterior-medial wall to be treated is identified and infiltrated with 2 ml of 1:200,000 adrenaline solution. This initial decongestion allows clear definition of the borders of the cartilage, especially in relation to the anterior-lateral wall corresponding to the TVPM. The clearly defined TVPM ensures that it is not overheated directly or indirectly, since the goal of the surgical procedure is to create anatomical conditions that permit improvement of TVPM contraction efficiency (Fig. 1).

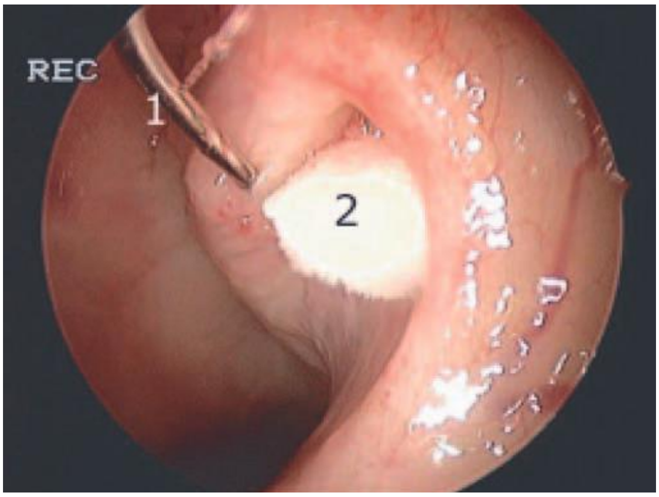

Fig. 1. Initial decongestion of the left Eustachian tube. (1) 1/200,000 adrenaline solution infiltration of the intraluminal mucosa of the posterior Eustachian tube. (2) Packing of the Eustachian tube entrance with a 1:100:000 adrenaline solution. (Courtesy O. Kujawski)

10. Surgical technique

A 4-mm diameter 30° rigid endoscope (Karl Storz) and the CO_2 laser guide or a 200-µm diode or KTP laser fibre is introduced into the operating field through the nasal or oral cavity, and advanced to the nasopharynx. Figure 2 shows an initial view of the Eustachian tube prior to commencing the procedure.

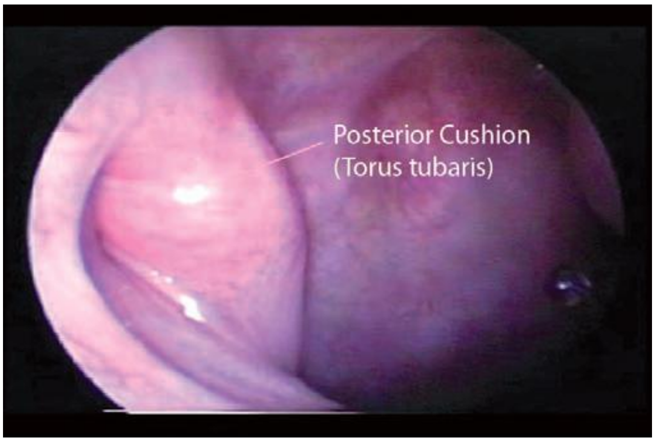

Fig. 2. 30º rigid endoscopic view of right laser Eustachian tuboplasty (LETP); initial view prior to commencing procedure. Note the bulging of the posterior cushion mucosa into the lumen.

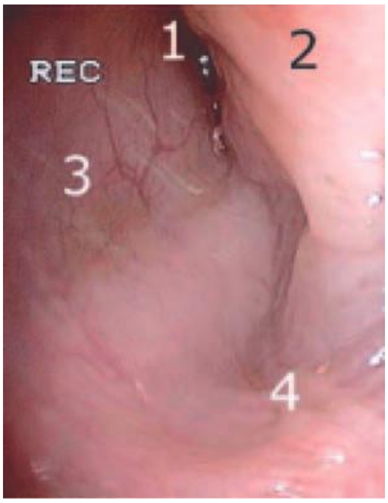

Fig. 3. Preoperative proximal endoscopic exposure of the right Eustachian tube. The limits typically begin from the free border of the posterior-medial wall (the tip of the torus tubaris) (2) and extend into the lumen to the point where the anterior and posterior mucosal surfaces oppose each other and create the functional valve of the Eustachian tube (1). (3) Tubal anterior wall with the TVPM from underneath. (4) Tubal floor with the LVPM from underneath. (Courtesy O. Kujawski)

The oral cavity is opened with a mouth gag, and the soft palate is lifted up with a silicone elastic tube in order to obtain secondary access to the operating field. A curved sinus antral suction is introduced through the mouth and brought to the entrance of the Eustachian tube. The surrounding tubal ostium is gently palpated with the suction tip in order to locate the medial cartilaginous lamina within the posterior cushion and evaluate tissue resistance. The posterior-medial wall is medially reflected to open the lumen to visualise its longitudinal axis. The limits of laser vaporisation will have been determined in part by the extent of disease and impairment seen at the time of preoperative video-endoscopic assessment. The limits will typically begin from the free border of the posterior-medial wall (the tip of the torus tubaris) and extend into the lumen to the point where the anterior and posterior mucosal surfaces oppose each other and create the functional valve of the Eustachian tube (Fig. 3). This distal limit corresponds to the end of the free portion of the tubal cartilage at the point where it becomes thinner and immobile. This transition point can be related to the length estimated between the free border of the posterior wall (torus tubae) and the Rosenmüller pit, but it should be confirmed by preoperative CT scanning.

11. Various lasers and their settings

11.1. The CO_2 laser

The CO_2 laser is used in superpulse mode. The power is set at 12 W with the exposure time in a repeat mode of a duty cycle of 0.05 seconds on and 0.05 seconds off.

11.2. The Diode laser

If the diode laser is used, a setting of 7 W is selected in a repeat mode of 0.2 seconds on and 0.08 seconds off, and the energy is applied in the *contact* mode, delivered via a 200-µm fibre. This allows precise vaporisation of the mucosa with a minimal thermal effect on the underlying structures bearing in mind the thinness of the cartilage.

11.3. The KTP laser

Diode pumped KTP laser settings are 2.5 W with pulses of 1.0 second. A suction catheter is passed transnasally into the opposite side of the nasopharynx for continual evacuation of smoke plume.

12. Laser vaporisation

The vaporisation starts at the free border of the posterior-medial wall (torus tubae) and follows the intratubal posterior-medial wall (Fig. 4). As the

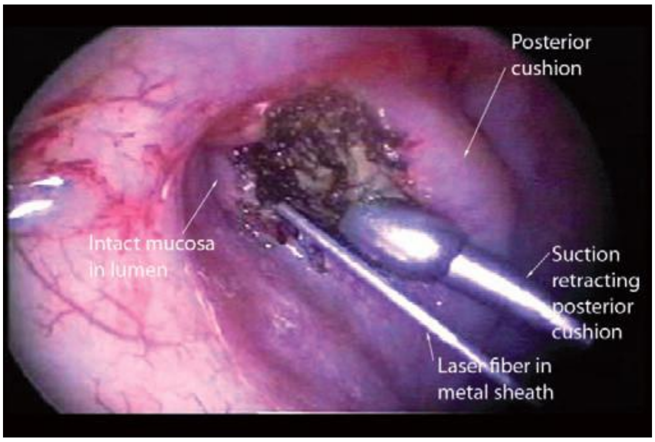
Posterior cushion
Intact mucosa in lumen
Suction retracting posterior cushion
Laser fiber in metal sheath

Fig. 4. Right laser Eustachian tuboplasty (LETP). Vaporised mucosa and cartilage of the posterior wall is clearly visible. A curved olive-tip suction is used to retract the posterior cushion medially. The 200-micron KTP fiber-delivered laser is being used to vaporise submucosa deep to the mucosa of the valve, undermining a flap that will heal in a medialised position.

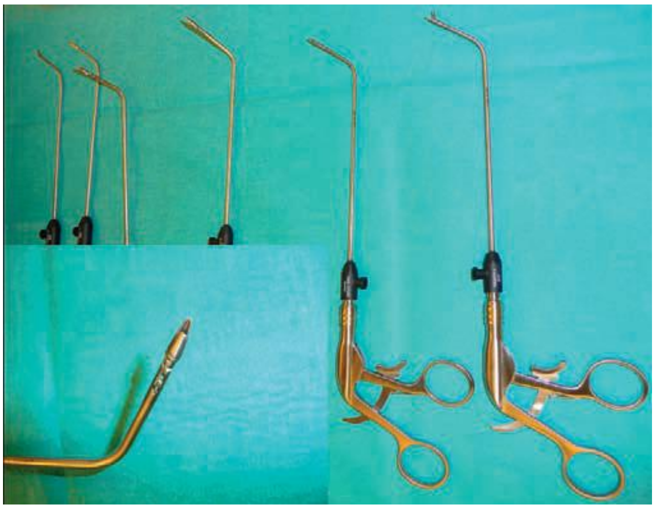

Fig 5. Curved Eustachian tube instruments for transoral approaches. Inset shows a close-up of the self-retaining retractor for dilation of the tubal orifice.

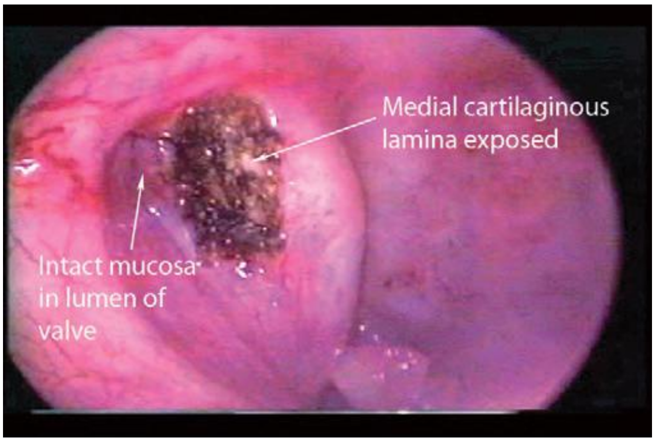

Fig. 6. Final wound at the end of Eustachian tuboplasty. Cartilage is exposed and resected as indicated. Mucosa is spared within the valve.

vaporisation progresses deeper into the lumen, a 90°-angled curved distending retractor (Karl Storz, Germany) (Fig. 5) may be used to dilate the nasopharyngeal orifice and valve of the Eustachian tube.

The distal limit of the laser treatment corresponds to the end of the free portion of the tubal cartilage at the point where it becomes thinner and immobile (Fig. 6). This transition point can be approximated to the length between the free border of the torus tubae and the Rosenmüller pit.

Absorbable hyaluronate gel, soaked in corticosteroid and topical antibiotic, is placed into the lumen to help medialise the mucosa flap (Fig. 7).

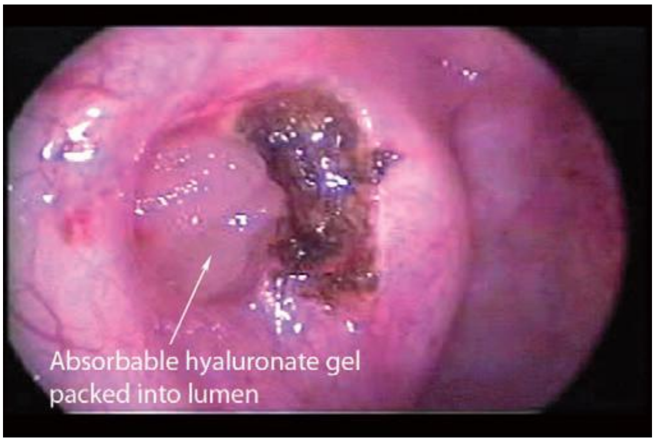

Fig. 7. Absorbable hyaluronate gel soaked in corticosteroid and topical antibiotic has been placed into the lumen to help medialise the mucosa flap.

13. Postoperative care

Intranasal corticosteroid sprays are routinely prescribed for the first three weeks following surgery. A follow-up examination and endoscopy of the Eustachian tube is done about ten days after surgery. The normal nasopharyngeal lining is restored after an average of six weeks following surgery. Comparison of pre- and postoperative biopsies of mucosa from the lumen of the nasopharyngeal orifice shows less inflammatory cells and more fibrosis in the mucosa, with return of normal pseudostratified epithelium. Secondary otalgia is uncommon. If there is a known underlying medical aetiology, such as atopy or reflux disease, ongoing medical treatment is indicated to minimise recurrence of tubal disease.

14. Surgical outcomes

A prospective study assessed 38 patients who underwent surgery using this technique for treatment of chronic Eustachian tube dysfunction (Kujawski, 2000; 2001). This group consisted of 23 males and 15 females aged 11-57 years. They suffered from fluctuant conductive deafness, tinnitus and otalgia, and presented with otitis media with effusion. The follow-up period lasted for 27-51 months. In none of the cases did postoperative bleeding occur. No secondary otalgia was reported. None of the treated patients developed postoperative patulous Eustachian tube or intraluminal synechia.

The 12-month follow-up evaluation was carried out on all 38 patients. After surgery, 71% of these patients noted an improvement in hearing. The severity of tinnitus decreased in 60% and otalgia in 86%. Twenty-five of the 38 patients (66%) who complained of recurrent otitis media remained symptom-free during the follow-up period of 12 months. Thirty-six months after surgery, none of the 32 remaining patients had experienced a recurrence. Five of 12 patients whose hobby was sport diving were able to resume this postoperatively without complications.

15. Conclusion

In conclusion, LETP is indicated in chronic Eustachian tube dysfunction causing conductive deafness, tinnitus, and recurrent otalgia. The improvement in episodes of recurrent otitis media with effusion, observed in this preliminary study, seems to indicate promise for this new type of prophylactic management in the prevention of this common middle ear pathology. In future, the scope of Eustachian tuboplasty could be extended to include postnasal neoplasm involving the Eustachian tube and congenital deformities of the cleft palate.

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MCQ – 37. Laser cartilaginous Eustachian tuboplasty

1. The Eustachian tube
   a. Is formed by the bony two third and the cartilaginous one third portion
   b. Is lined by pseudostratified respiratory epithelium along its entire length
   c. Tensor veli palatini muscle is its main dilator
   d. Levator veli palatini controls the movement of the medial cartilaginous lamina whereas the tensor veli palatini controls the movement of the lateral lamina
   e. Levator veli palatini controls the movement of the lateral lamina whereas the tensor veli palatine controls the movement of the medial lamina

2. During swallowing and yawning
   a. The tube opens due to movement of the lateral lamina medially and upwards
   b. The tube opens due to movement of the medial lamina medially and upwards
   c. The tube opens due to movement of the medial lamina laterally and upwards
   d. The tube opens due to movement of the lateral lamina laterally and downwards
   e. The force of the current of air opens the tube mechanically and then aided by the peritubal muscles with dynamic contraction.

3. The tensor veli palatini muscle acts on
   a. The postero-lateral wall
   b. The antero-lateral wall
   c. The postero-medial wall
   d. The antero-medial wall
   e. All of the above

4. Dysfunction of the Eustachian tube may result from
   a. Mechanical obstruction due to hypertrophy of the adenoids
   b. barotrauma
   c. Trauma during surgery for choanal atresia
   d. Oedema of the mucosal lining
   e. Dysfunction of the levator and / or tensor veli palatini muscles

5. During barotrauma
   a. Increased pressure on the surface of the tympanic membrane causes it to collapse and results in symptoms
   b. Failure of the tube to open results in lack of equalisation of the pressure in the middle ear to counter act against increased external pressure
   c. A combination of depletion of air in the middle ear by absorption and lack of supply of air from the closed Eustachian tube cause symptoms.
   d. Haemotympanum reduces otalgia
   e. Haemotympanum worsens otalgia

6. Predisposing causes for Eustachian dysfunction include
   a. History of nasal allergy
   b. Unilateral choanal atresia
   c. Antrochoanal polyp
   d. Reflux
   e. URTI

7. Tuboplasty is indicated
    a. In all cases of tubal dysfunction
    b. In all cases of cleft palate
    c. In cases where medical management has failed
    d. In cases of collapsed fixed retraction pocket
    e. In cases where peri-tubal musculature is dysfunctional

8. Laser tuboplasty
    a. Is aimed at reducing the oedematous mucosa from the posterior tubal wall
    b. Is aimed at reducing the oedematous mucosa from the anterior tubal wall
    c. Is aimed at reducing the oedematous mucosa from both the posterior and anterior tubal wall
    d. Thinning the cartilage of the posterior lamina to enhance the dilatory effect of the peritubal muscles
    e. Aimed at widening the narrowest portion – the isthmus

9. The preferred lasers for tuboplasty have the following properties
    a. Absorption by sub-mucosal fat
    b. Shallow depth of penetration
    c. Fibre-transmissibility
    d. Emission in visible spectrum
    e. High power output

10. The postero-lateral limit of the vaporisation of the mucosa is
    a. Up to the isthmus
    b. Where the mucosa changes from pseudostratified respiratory epithelium to cuboidal respiratory epithelium
    c. Where the mucosa of the antero-medial and postero-medial walls approximate
    d. About 10 mm from the torus tubaris

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SECTION V: Oropharyngeal and Head & Neck Surgery

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Chapter 38

Lasers in oral surgery

C. Hopper

1. Introduction

Since the 1970's, lasers have been increasingly used in oral and maxillofacial surgery. Their effect on tissue is determined by their wavelength and the tissue specific absorption. Lasers can be used for evaporation, excision and coagulation of tissue. The commonly used lasers include carbon dioxide (CO_2), neodymium:yttrium-aluminium-garnet (Nd:YAG) and Argon lasers. Also, light and laser light are used for the diagnosis of mucosal lesions. By using different excitation wavelength autofluorescence, abnormal lesions can be detected and analysed (Roodenburg *et al*., 2002).

Literature in oral oncology continues to support the use of lasers in surgery of malignant and premalignant lesions. Several authorities have explored the indications, techniques, results, and benefit and risk issues of lasers used in this field. CO_2 laser is primarily suited for trans-oral resections of premalignant and early oral carcinomas (Fig. 1). The five-year survival rates and the postoperative oral function with the carbon dioxide laser are comparable with those obtained following conventional surgical methods. The Nd:YAG laser, because of its unique characteristics (its ability to coagulate and ablate; although it is not as precise a cutting tool as the CO_2 laser), has specific advantage in the treatment of large oral vascular malformations (Burkey and Garrett, 2002).

2. Comparison with conventional methods

Compared to conventional surgery, epithelial regeneration and wound re-epitheliasation are delayed (Patel, 1964, Roodenburg *et al.*, 2002; Burkey and Garrett, 2002). However, there is no detrimental effect on eventual surgical outcome.

Tuncer *et al*. (2010) compared conventional surgery and laser surgery on oral soft tissue pathology. They evaluated the effect of collateral thermal damage on histopathological diagnosis, pain control and postoperative complications. Histological examination of the specimens showed that collateral thermal damage on the incision line did not have adverse effect on the histopathological diagnosis. Pain control was better with lasers. No intra- or postoperative complications were seen in both groups.

3. Advantages of laser management of oral pathology

The use of lasers in the management of oral disorders has been implemented for several years. The advantages of this approach include minimal damage to adjacent tissue, delayed acute inflammatory reaction and reduced myofibroblast activity, leading to reduced wound contraction and scarring. Reduction of collagen in the postoperative phase maintains soft tissue movement. The laser-treated area can be left exposed to granulate, thus obviating any need for skin grafting or wound dressing.

Since dissection usually follows the approach of

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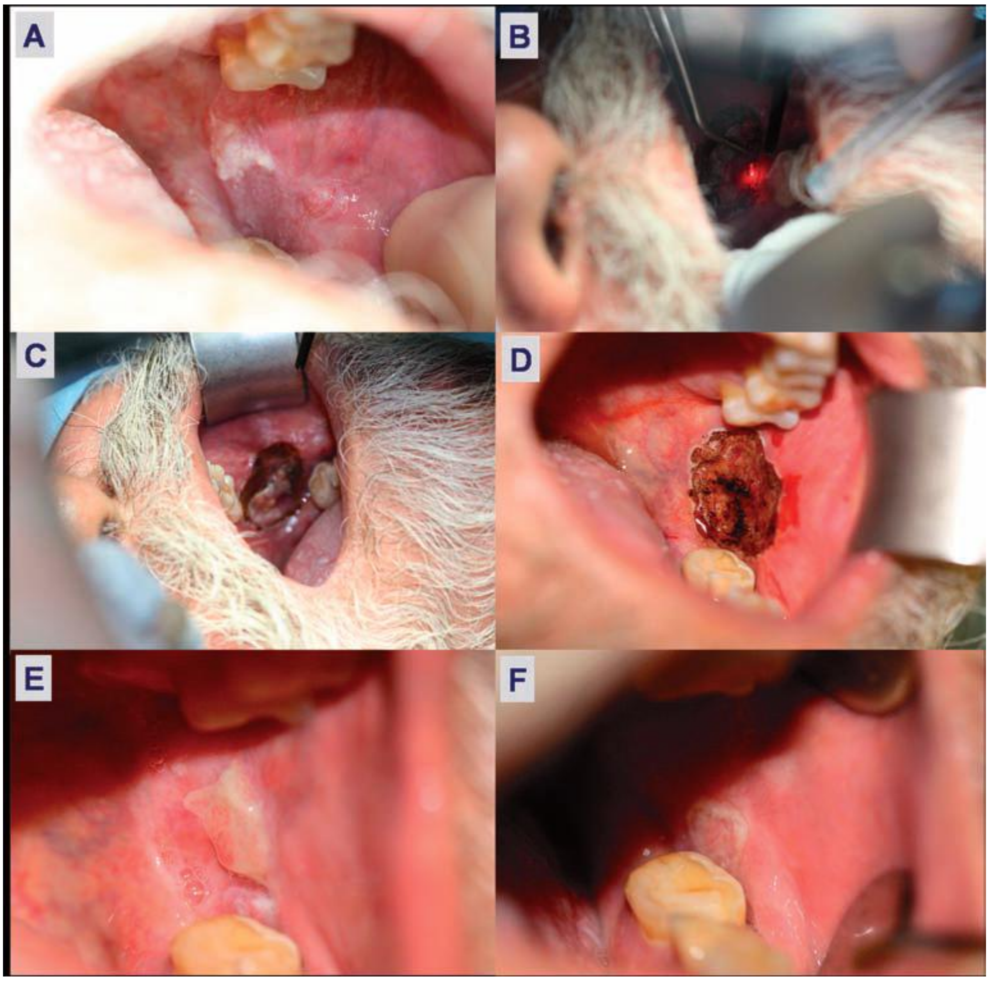

Fig. 1. A. Patient presented with non-homogenous leukoplakia of the posterior buccal area and the retromolar trigone. B. CO_2 laser excision of the lesion carried out under general anaesthesia. C. Three margins (superior, anterior and posterior) have been excised and released prior to release of the inferior margin. D. Complete lesion excision and subsequent laser of the base to achieve haemostasis. E. One week post excision showing good healing with minimal frictional keratosis. F. One month post excision showing normal oral mucosal with regression of keratosis.

'en block' removal of tumour tissue, rather than anatomically based dissection, more normal oral tissues can be preserved. This results in greater preservation of oral function such as swallowing, speech, etc.

When laser is used, the operating time is reduced. Patients require a shorter hospital stay. The laser procedure is thus cost-effective. Should there be a recurrence or malignant transformation, laser can be used again. Laser usage also does not impose any limitations to implementing multi-modal management with conventional surgery, chemo-radiation and/or photodynamic therapy (Patel, 1964; Roodenburg *et al.*, 2002; Burkey and Garrett, 2002; Bornstein *et al.*, 2005).

Bornstein *et al.* (2005) assessed 139 patients with 164 intraoral pathological lesions treated with laser. Intra-operative pain control was achieved with topical anaesthesia alone in almost a third of cases. In the remaining 111 lesions, a local anaesthetic was necessary. For pain relief after the operation, 101 patients (72.7%) used an adhesive wound paste, without any additional oral analgesic. The thermal damage from the laser on the borders of the biopsy specimens did not interfere with the pathologist's establishment of a firm diagnosis. This suggests that laser surgery is an appropriate instrument for excisional biopsies of oral soft tissue lesions.

4. Inadvertent laser damage

Inadvertent laser damage to the patient or operating theatre staff is an acknowledged risk. However, no data exists to verify the safety margin of commonly employed precautions. A study by Ahmed *et al.* (2010) assessed the safety margins of protective strategies commonly adopted when using lasers to resect tumours of the head and neck. Gauze swabs, neurosurgical patties, surgical gloves, paper drapes and conventional PVC endotracheal (ET) tubes were tested against the following laser variables: power, beam characteristics and angle of beam incidence (90 and 45 degrees). Laser penetration time through the material under test was recorded in seconds (s). The materials were tested dry and some, where appropriate, were tested wet. The results demonstrated dry gauze swabs, neurosurgical patties and paper drapes provided 0 s protection at 2 W (lowest power). However, when wet, the laser failed to penetrate the swabs and neurosurgical patties, even after 180 s of continuous application. Gloves (single or double layer), and ET PVC cuffs were penetrated in less than 1 s at 2 W. Time to penetrate a size 6.0 PVC ET tube at 2 W continuous setting increased from <1 s at 90 degrees to 42 s at 45 degrees.

5. Using CO_2 laser for oral pathology

CO_2 laser is the most efficient cutting modality for mucosa when used as focused beam. Most of the energy is absorbed on the surface and the tissue is lost by vaporisation. However, some of the energy is conducted in the deeper layers, beyond the zone of vaporisation. The conducted energy does not have the same power as the impacted energy. This energy causes a zone of coagulation, of between 200 and 400 µm width, sufficient to provide intraoperative haemostasis of small blood vessels of the oral tissues (*i.e.*, buccal mucosa and lips). However, it is not effective for haemostasis of vessels larger than 0.5 mm in diameter (*e.g.*, vessels in the tongue). and the beam must be used in defocus mode to affect haemostasis, diathermy is also used if necessary.

Caution should be taken when using lasers around dental tissue as it is strongly absorbed by hydroxyapatite and may produce micro-cracks not visible to the naked eye. These structures can be shielded when performing laser procedures to prevent long-term problems. It is interesting to know that both diode and KTP lasers are safe to use around dental structures as they have a much lower absorption in calcified tissue.

A hand piece is usually used to deliver the laser beam to the oral tissues in preference to the microscope with micromanipulator, which is indispensible for pharyngeal and laryngeal surgery. The hand piece allows high level of manoeuvrability and high power density.

The following steps are recommended when dealing with a lesion in the oral cavity (Fig. 1):

- The area to be excised is identified and marked. A local anaesthetic solution with a vasoconstrictor is infused peripherally to provide pain relief for procedures under local anaesthesia or sedation, and also to control pain postoperatively. The vasoconstrictor provides a relatively blood-free surgical field.
- Surrounding non-target tissues are protected by draping and covering them with wet gauze which also acts as heat sink, in case the laser inadvertently strikes these areas.
- A cut is made in the normal tissue in the vicinity of the lesion. The cut is deepened and the lesion is lifted with a pair of toothed forceps or skin hooks. The tissues underneath the lesion are stretched, in the same way as in cold instrument surgery. The vaporising action of the laser is far more efficient on stretched tissues. Failure to stretch the tissue maximally will result in drying and charring of the tissue and inefficient vaporisation.
- Although stretching of tissues is important for efficient vaporisation and progress of surgical excision, excessive stretching distorts anatomy. It is therefore advisable to place the lesion back on its bed and orient again frequently to optimise excision.
- The wound is then wiped with a wet swab to remove any loose tissue and char. The excised area is inspected for any fresh bleeding. Oozing from small vessels can be effectively controlled by using the laser in defocus beam, in a paint brush fashion, on the whole of the wound surface. A coagulum thus formed provides not only postoperative haemostasis, but also a barrier for the wound infection. Bleeding from larger vessels is controlled with diathermy. Occasionally, coagulation packs can be sutured to the base to stop any bleeding. Sutures are not usually recommended following laser surgery since they may induce tissue contraction and fibrosis.
- Resected specimen is oriented and sent for histopathology.

6. Conclusion

In addition to the various oral lesions, the management of patients with sleep apnoea, temporomandibular joint derangements, dental implants, premalignant and malignant lesions, and posttraumatic facial scarring has improved significantly with the advent of laser surgery. As further laser systems develop and their technology become more advanced, a thorough understanding of the principles of their use is paramount to ensure safe and effective patient care (Strauss and Fallon, 2004).

Over the past few decades, the use of lasers among oral and maxillofacial surgeons has grown dramatically. Their evolution within the specialty not only has broadened current surgical options for treatment, but also contributed to a variety of new procedures that are now a commonplace in oral and maxillofacial surgery.

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MCQ – 38. Lasers in oral surgery

1. For oral vascular malformations, the most appropriate laser is
    a. None
    b. CO_2
    c. Nd:YAG
    d. Diode
    e. KTP

2. When compared to the convention surgical instrumentation and the laser
    a. Collateral thermal damage zone produced by the laser interferes with histological diagnosis
    b. Pain control is better with the laser
    c. Wound healing is quicker with the laser
    d. The wound needs grafting when laser is used
    e. Laser wound shows less contraction and therefore function preservation is superior

3. Inadvertent laser strike results in
    a. Damage to teeth
    b. Ignition of dry swabs
    c. Faster ignition of anaesthetic tube at high power
    d. Ignition of dry paper drapes
    e. All of the above

4. During laser strikes
    a. Stretching tissue results in faster excision speed
    b. Stretching tissue results in distortion of anatomy
    c. Stretching tissue results in spread of energy in to adjacent tissue and interferes with histo-pathological diagnosis
    d. Produces excessive charring
    e. All of the above

5. If a coagulum is formed on the excised bed
    a. It should be meticulously removed to encourage re-epithelialisation
    b. It may potentially hide the bleeders and therefore it should be wiped clean and the bed inspected again
    c. It protects the operative site from infection
    d. It prevents spread of micrometastases
    e. It causes increased postoperative pain due to infection at the operation site resulting from excessive sloughing

Chapter 39

The use of carbon dioxide laser in the management of oral pathology

W. Jerjes and C. Hopper

1. Introduction

The CO_2 laser was one of the earliest gas lasers invented by Kumar Patel of Bell Labs in 1963, and it still remains the most useful lasers in oral surgery practice. CO_2 laser is by far the highest-power continuous wave laser, ideal for oral surgical procedures since its energy is maximally absorbed by water, the main chromophore in the oral tissue.

Since the early 1970s, CO_2 laser energy has proved to be an effective method of treatment for patients with several types of oral lesions, including *early* squamous cell carcinoma (Fig. 1). Laser has been used as a preferred treatment option for oral leukoplakia since the mid 1980s. Morphological and functional recovery following laser surgery is superior when compared with conventional cold instrumentation surgery and electrocautery.

2. Laser surgery: Superior preservation of function following laser excision

Ishi *et al*. (2005) compared the results of partial glossectomy in rabbits:

- In group one, the excised edges of the wound were left unsutured after partial glossectomy with the CO_2 laser excision
- In group two, the wound was closed after CO_2 laser surgery
- In group 3, a control group, the wound was closed after partial glossectomy with electrocautery.

The results were assessed at two, four and eight weeks interval postoperatively. There was a significant difference in the tongue width between groups 1 and 3 at each time point. There was also a significant difference in the tongue width between groups 2 and 3 at eight weeks postoperatively. Visually and histologically, the scar tissue of the wound was extensive in the control group, whereas it was localized in the laser group. They concluded that postoperative *dysfunction* was reduced when excised edges were left unsutured after partial glossectomy with the CO_2 laser, and therefore, suturing of the excised edges is not necessary, nor is it advisable.

3. Potentially malignant oral disorders

The term 'dysplasia' is used to denote histopathological changes associated with an increased risk of malignant tranformation. The presence of dysplastic areas in the epithelium of the upper aerodigestive tract is believed to be associated with a likely progression to cancer. The individual cellular changes are referred to as 'atypia'.

The formation of homogenous leukoplakia, non-homogenous leukoplakia and erythroplakia can be associated with dysplastic changes although, clinically, oral epithelial dysplasia is not associated with any specific diagnostic appearance. The clinical type of leukoplakia has a bearing on the prognosis, since the non-homogeneous leukoplakias containing an erythematous, nodular, and/or verrucous component have four to five times higher risk of malignant change when compared to the homogeneous ones (Bornstein *et al*., 2005).

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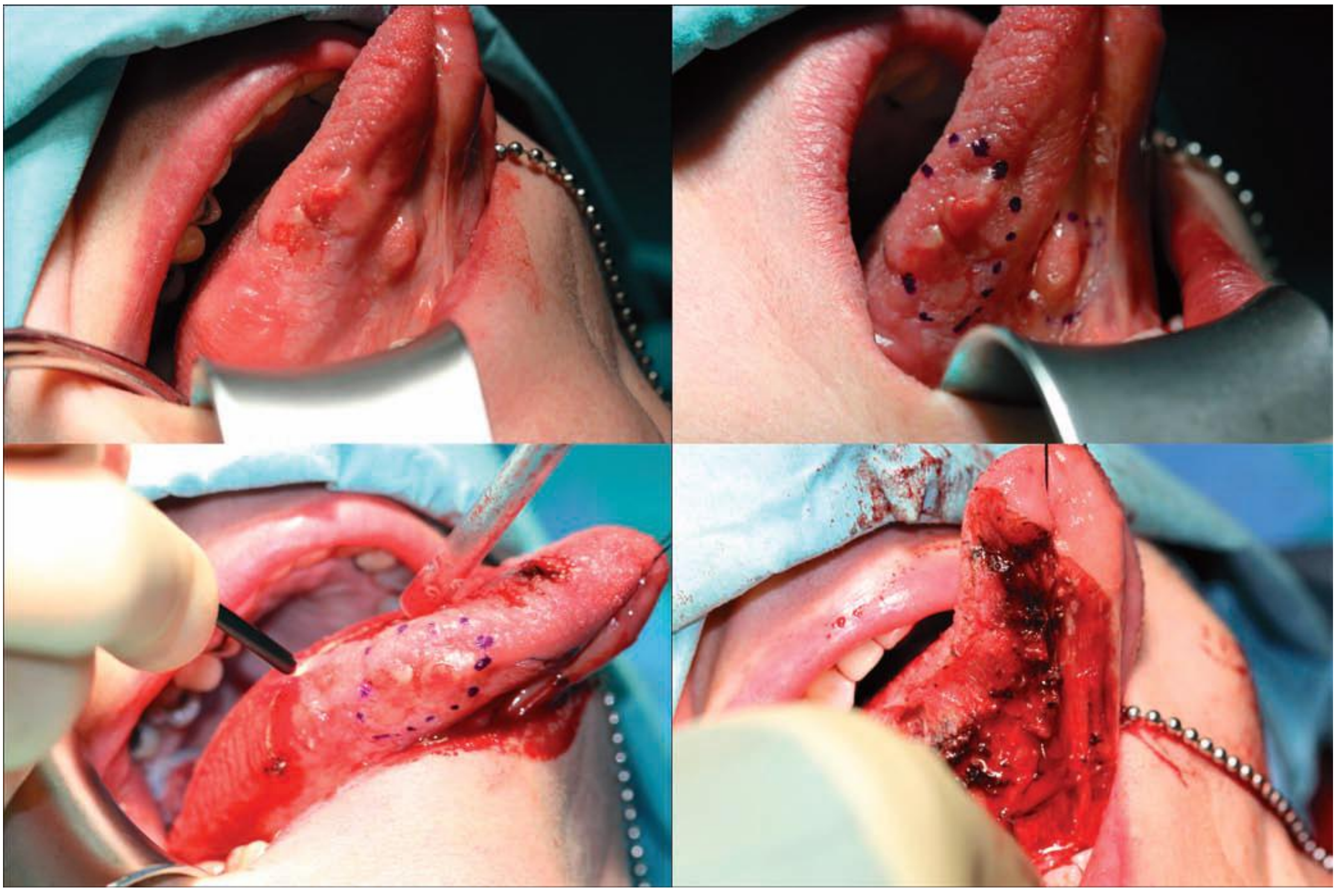

Fig. 1. CO_2 laser excision of tongue cancer. Top left: patient presented with a multi-nodular lesion of the ventrolateral tongue. Incisional biopsy confirmed squamous cell carcinoma. Staging of the patient revealed that there was no nodal involvement or distant metastasis. The patient elected to have the tumour excised with CO_2 laser under general anaesthesia. Top right: the nodules are identified and marked with an ink prior to excision. Bottom left: intraoperative CO_2 laser excision of the tumour. Bottom right: complete tumour excision and laser of the base to achieve haemostasis.

3.1. Literature review: Oral dysplasia

According to published reports in the literature (see below), in comparison to number of multi-variate factors, use of laser does not additionally influence outcomes in patients with oral leukoplakia. On the other hand, although the benefits of CO_2 laser surgery in the management of oral dysplasias have been evaluated, little consideration has been given to the factors which may influence treatment outcome, especially amongst patients developing recurrence or malignant transformation.

Hamadah and Thomson (2009) assessed the outcome of 78 patients undergoing CO_2 laser excision of newly diagnosed single oral dysplasias and the influence of clinico-pathological parameters, sociodemographic factors and the presence or absence of residual dysplasia in excision margins. Their results showed that there was *no* statistically significant association between patients' age, gender, lesion appearance, site of origin, histopathological grading, presence of dysplasia in resection margins, or alcohol consumption and clinical outcome. Smokers, however, were at significantly higher risk of recurrence of dysplasia compared to ex-smokers or non-smokers.

Chandu and Smith (2005) assessed 43 patients with 73 primary oral leukoplakia for outcome and factors affecting survival. It was postulated that alcohol consumption and previous malignancy are significant prognostic indicators. Continuation to smoking as a risk factor approached significance. Results from this study were comparable to other studies using other conventional modalities.

Van der Hem *et al*. (2005) reported on the outcome of a group of 200 patients with 282 oral leukoplakias, who were treated by CO_2 laser vaporisation. In a follow-up period of 52 months, only 28 (9.9%) local recurrences were observed whereas 251 treated leukoplakias (89.0%) did not show any recurrence. In three patients (1.1%), transformation to squamous cell carcinoma were identified.

Schoelch *et al*. (1999) assessed seventy consecutive laser-treated patients with oral leukoplakia. Thirty-nine patients had some degree of microscopic dysplasia. Six patients had high-risk proliferative verrucous leukoplakia. The CO_2 and Nd:YAG lasers were used to excise lesions. The authors reported complete control in 29 patients. Nineteen patients had small recurrences which were removed with further laser surgery resulting in control of their disease. Two patients had extensive recurrences whereas five patients developed full-fledged squamous cell carcinoma at the lesion site. Verrucous lesions had a particularly high rate of recurrence (83%), nine out of twelve patients had their lesions eventually controlled with surgery.

Chiesa *et al*. (1993) retrospectively analysed 167 consecutive patients with oral leukoplakias operated on by CO_2 laser resection. Within five years, 69 patients had at least one unfavourable event. These included 31 local relapses, 27 new leukoplakias, five oral carcinomas and six other neoplasms elsewhere. The Cox regression analysis showed that age of operated patients and the size of resected lesion are significant predictive factors in the development of relapses, new leukoplakias and carcinoma.

Thomson and Wylie (2002) reviewed the records of 57 consecutive laser-treated patients presenting over a four-year period with histologically confirmed dysplastic lesions. Leukoplakias were the commonest clinical lesions (69%), whilst the floor of the mouth was the most frequent anatomical site (42%). Laser surgery successfully excised 55 precancerous lesions, 11 of which exhibited more severe dysplasia or neoplasia compared with initial biopsy. Of these patients, 76% remained disease-free, whilst 24% developed new dysplastic lesions at distinct or multiple sites, often exhibiting increased dysplasia. Of the patients experiencing recurrence, 7% developed oral squamous cell carcinoma (OSCC), whilst a further 3.5% presented with other aerodigestive tract cancers (2002).

Laser is thus an elegant tool for surgery of oral leukoplakia. It plays an important integral role as a part of an overall management strategy which includes careful clinical follow up, patient education to eliminate risk factors, report suspicious lesions, and biopsy these; and any other significant lesions as appropriate. However, recurrence and progression of untreated areas to cancer remains a risk.

4. Oral cancer

The incidence of OSCC remains high (Bagan and Scully, 2008). Oral and oro-pharyngeal carcinomas rank the sixth most common cancers in the world (Warnakulasuriya, 2009). Despite advances in early diagnosis and management, there has been no significant improvement in the survival rate during the past 20 years and five-year survival rates remains dismally at 45-50% (Bagan and Scully, 2008). Prognosis depends or varies with primary site, nodal involvement, tumour thickness, and the status of the surgical margins. Moreover, the cumulative effects of tobacco, betel nut and alcohol decrease the survival rate (Garzino-Demo *et al*., 2006).

Surgical modality remains a time-honoured mode of initial definitive treatment for the majority of OSCC patients (Shah and Gil, 2009). The aim of surgical ablation for OSCC is the removal of all viable tumour tissue. This intuitively is associated with better overall prognosis. Resection of the primary tumour is advocated along with dissection and removal of the cervical lymphatic chain, when indicated. Reconstruction of the defect can be by loco-regional repair or by distant free tissue transfer. Elective neck dissection is employed when the risk of cervical involvement is ≥ 15-20% (Weiss *et al*., 1994; Kowalski and Medina, 1998; Huang *et al*., 2009). Therapeutic neck dissection is of high benefit in patients with regional metastasis and has also been of benefit in patients with N0 neck (Fakih *et al*., 1989; Haddadin *et al*, 1999). Nevertheless, controversies continue to arise in patients with T1N0 disease.

Radiotherapy plays a key role in the management of early-stage and locally advanced OSCC, either alone or more frequently, combined with surgery and/or chemotherapy (Mazeron *et al*., 2009). The role of chemotherapy in the management of OSCC continues to evolve. Loco-regional advanced OSCC can respond to chemotherapy, as an induction or palliative treatment, with irradiation. The current most favoured regimens for induction chemotherapy include cisplatin/infusional 5-fluorouracil/docetaxel (Specenier and Vermorken, 2009).

Photodynamic therapy (PDT) is a minimally invasive procedure for treating a variety of tumours. The treatment can be delivered under local or general anaesthesia, and the delivery method includes surface illumination or interstitial application (iPDT). This therapy can be repeated as required since there is no cumulative toxicity. It can also be used before or after any of the conventional treatment modalities.

One study reported excellent outcome following the use of PDT in 11 patients in whom 'field cancerisation' had occurred in the oral cavity (Grant *et al*., 1993). In another study (Fan *et al*., 1997), nineteen patients with histologically proven oral cancer (eight with field-change disease) and one with severe dysplasia, were sensitised and treated with m-tetrahydroxyphenylchlorin (mTHPC-PDT). The results were assessed clinically and histologically. Most patients healed very well, but tongue tethering was seen in one patient and in another, there was necrosis in normal areas due to light scattering within the mouth.

4.1. Oral cancer: CO_2 laser – literature review

Since the early seventies of the last century, CO_2 laser has proved to be an effective method of treatment for patients with several types of oral lesions. However, few reports have appeared in the literature regarding the use of CO_2 in oral squamous cell carcinoma.

Thirty-seven consecutive patients with cancer of the anterior two-thirds of the tongue without clinical neck lymph nodes or distant metastasis were treated with co-axially delivered CO_2 laser with an operating microscope (Wang *et al*., 2001). Of the 28 patients in the T1/T2 groups, 26 patients did not receive postoperative radiotherapy. The local control rate in all 37 patients at five years was 93.6%. No local recurrence occurred in the T1 or T2 cases. Nine patients developed neck recurrence and the neck control rate at five years was 74.6%. Eight of these nine patients were salvaged by surgery with adjuvant radiotherapy, and six of them finally achieved disease-free status. The five-year disease-free survival rate was 88%.

Ishii *et al*. (2002) compared the rate of recurrence and subsequent metastasis between one group of patients treated with laser surgery and another group treated with radiotherapy (interstitial implant). Laser monotherapy with CO_2 laser was carried out on 18 cases for squamous cell carcinoma of the mobile tongue. The cure rate of primary tumour was 83.3%. One patient had subsequent metastasis after laser surgery. No differences were found in the rate of recurrence between the two groups.

Werner *et al*. (2002) reviewed the published data on oncologic laser surgery for the treatment of head and neck carcinoma, along with their own clinical experience of transoral laser surgery for the treatment of carcinomas of the oral cavity, pharynx, and larynx. They concluded that laser surgery has achieved a key position in minimally invasive treatment concepts in the ears, nose, and throat area, and especially for the treatment of malignancy of the upper aerodigestive tract.

5. Prospective studies, authors' experience

Prospective studies were undertaken at the Department of Surgery of University College London Medical School on patients suffering from potentially malignant oral disorders, and oral cancers.

5.1. Potentially malignant oral disorders

In a prospective study carried out at the Department of Surgery of University College London Medical School, a total of 123 oral dysplastic lesions from 77 consecutive patients were treated with CO_2 laser (resection and/or ablation). The average age was 58 ± 4.8 years. All patients had uneventful recovery. Comparisons with the clinical and histopathological features and rate of recurrence as well as malignant transformation were made. The patients were followed up for a mean period of 6.4 years, and biopsies taken where changes suggestive of malignant transformation were noted.

Homogenous leukoplakias were identified in 31 patients. 34 patients had non-homogenous leukoplakias. Twelve patients had erythroplakias. Ex- and lifelong smokers formed 88.3% of the recruited patients. Current smokers and drinkers formed 55.8% of the cohort. Erythroplakias were solely identified in heavy lifelong smokers. The most common primary anatomical locations were the lateral border of tongue, floor of mouth and buccal mucosa. Moderate dysplasia was identified in 42 patients while 18 patients showed severe dysplasia.

Laser resection was employed in selected cases (68 patients). The margins were clear in 53 patients. The rest of the patients had laser ablation. The rate of recurrence had no significant association with the location or the severity of epithelial dysplasia. The rate of first recurrence after laser surgery was 19.5%. Malignant transformation was observed in 8 patients (10.4%), in the tongue and the floor of mouth. Recurrence and malignant transformation was mainly identified in erythroplakias and non-homogenous leukoplakias.

5.2. Oral cancer

A prospective study was carried out to determine the oncological outcomes following transoral CO_2 laser resection of T1/T2 N0 OSCC. Three-year disease-specific survival and disease-free survival were evaluated. The data included a range of clinical, operative and histopathological variables related to the status of the surgical margins. Data collection also included recurrence, cause of death, date of death and last clinic review.

Ninety patients (64 males and 26 females) participated in this study. Their mean age at the initial diagnosis of OSCC was 63.5 years. Two-thirds of the patients were Caucasians. The common presentation was an ulcer of the tongue, floor of mouth or buccal mucosa. Current and ex-smokers represented 82.2% of the cohort; while current and ex-drinkers were 78.9%. Co-morbidities included history of oral lichen planus, oral submucous fibrosis, immunodeficiency and oral dysplasia. Clinically 81 patients had T1N0 disease while nine had T2N0 disease.

Pathological analysis revealed that nearly half of the patients had moderately differentiated OSCC. Further 18 had moderate to poorly differentiated and 19 had poorly differentiated carcinoma. Study of the tumour margins showed that a mean depth of invasion was 5.7 mm. Primary tumour clearance was achieved in 73 patients. Recurrence was identified in 11 (12%) patients. The mean age of first recurrence group was 76.4 years. Most common clinical presentation in the recurrence group was an ulcer involving the tongue or buccal mucosa; most commonly identified in current or ex-smokers or drinkers. Recurrence was identified in patients whom clinical and radiological staging revealed involvement of the locoregional lymphnodes. The surgical margins in this group were also evaluated following re-laser excision or conventional surgical excision ± neck dissection.

Follow up showed a three-year survival of 86.7%. Of the 12 patients who died, nine died from causes not related to their cancer, two from locoregional spread and one from pulmonary metastasis.

6. Benefit and risk issue

The advantages of laser therapy include minimal postoperative pain, conservative site-specific minimally invasive surgery and elimination of need for sutures. Laser excision was well tolerated by patients with no intraoperative or postoperative adverse effects. All patients healed with no post surgically induced loss of function. Both CO_2 and Nd:YAG lasers offered equitable surgical options when performing excision of benign intraoral lesions (White *et al*., 1998).

The bystander collateral thermal damage of the margin may pose some difficulty in pathological interpretation of laser margins. Photocoagulation of proteins may mask or alter surface epitopes, rendering some immunohistochemical stain less useful. These issues were addressed by revising protocol: resected specimen was sent separately, followed by final-margin specimen.

Obviously, a highly experienced sub-speciality head-and-neck pathologist is an essential member of the team. There is also an uncompromising need for good communication between the operating room and the pathology department. This can range from annotated photo-documentation and narrated video to having physical presence of the pathologist in the theatre room.

The intention of care is to detect, treat and prevent malignant transformation. Several management protocols have been recommended. However, no large trials have shown an ultimate, reliable intervention. No evidence base exists on which to reliably recommend treatment options.

Surgical removal of oral dysplastic lesion seems one realistic option. Many professionals use scalpel, laser, or cryoprobe as a surgical tool of their choice. In our opinion, laser excision offers preferred option to electrofulguration for reasons stated above. It has been argued that such operative interventions aggravate dysplasia and that surgical removal of aneuploidic lesions does not improve mortality rates.

7. Discussion

Literature in head and neck oncology continues to support the use of lasers for surgical removal of malignant lesions of the oral cavity. The five-year survival rates, and the postoperative function with the laser are at least as comparable as those obtained using other surgical methods (Burkey, 1996).

CO_2 laser resection has become the elective treatment for small oral and oropharyngeal carcinomas. The reasons are the lack of need to undertake reconstructive surgery, scarce cicatricial retraction, and the excellent postoperative evolution (Villarreal Renedo *et al*., 2004).

A further improvement of outcome might be expected by the combination of adjuvant radiotherapy with concomitant platinum-based chemotherapy. Pradier *et al*. (2005) reported a study which included 208 patients with advanced squamous cell carcinoma of the head and neck. Following CO_2 laser resection, patients were given postoperative radiotherapy. Primary sites included oral cavity, oropharynx, larynx and hypopharynx. In this series, transoral laser surgery in combination with adjuvant radiotherapy in patients with advanced head-and-neck tumours resulted in locoregional control and disease specific survival rates similar to those reported for radical surgery followed by radiotherapy.

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MCQ – 39. The use of carbon dioxide laser in the management of oral pathology

1. Following CO_2 laser excision for lesion of the tongue
    a. The bed should be sutured if possible in order to achieve a good functional result
    b. The bed should be left to heal with secondary healing to achieve a good functional result
    c. Grafting should be undertaken to achieve a good mobility of the tongue
    d. The need for grafting is decided on case to case basis

2. Laser management of leukoplakia
    a. Provides a complete cure for leukplakic lesions
    b. Requires patient education to report ‘suspicious’ lesions
    c. Forms an integral part of the overall management
    d. Does not require a follow up if all visible and suspicious lesions are fully excised, and biopsy confirms benign nature
    e. Requires concomitant management of risk factors to prevent recurrence / malignant transformation

3. In oral squamous cell carcinoma
    a. Recurrence rate is low with CO_2 laser ‘monotherapy’ management
    b. Recurrence rate is low with radiotherapy (interstitial implants) management
    c. Recurrence rate is low with combined monotherapy CO_2 laser and radiotherapy management
    d. Both methods, individually used, give similar results for rate of recurrence

4. The commonest anatomical site for oral dysplastic lesions is
    a. Dorsum of the tongue
    b. Lateral border of the tongue
    c. Floor of mouth
    d. Buccal mucosa
    e. Posterior third of the tongue

5. Collateral thermal damage with the CO_2 laser
    a. Can interfere with state of clearance
    b. Requires an experienced head and neck pathologists
    c. Requires a protocol for communication to convey precise information
    d. Requires a separate final margin specimen to confirm clearance
    e. All of the above

6. The CO_2 laser advantages over other surgical or radio-therapeutic modality for oral cancer include
    a. Less postoperative pain
    b. Quicker healing
    c. Better control of regional spread
    d. Better functional results
    e. Cost-effectiveness

Chapter 40

CO_2 laser endoscopic microsurgery of Zenker's pharyngo-oesophageal diverticulum

M. Remacle and V. Oswal

1. Introduction

Zenker's diverticulum (ZD) is a pouch protruding posteriorly above the upper oesophageal sphincter, in Killian's triangle, an area of relative weakness (Achkar, 1998). Over the past decades, the treatment of ZD has undergone changes, hand-in-hand with an understanding of its aetiology and technological advances (Sideris *et al.*, 1999). Incomplete relaxation of the upper oesophageal sphincter is now regarded as the key aetiological factor in the development of high pharyngeal pressures, with the subsequent outpouching responsible for formation of the diverticulum. Many studies have justified myotomy as an essential component in the treatment of pharyngo-oesophageal diverticula. Although gastro-oesophageal reflux may be responsible for many throat symptoms, the relationship between reflux and the pathogenesis of ZD is speculative.

1.1. Pseudodiverticulum

Lippert *et al.* (1999) report diverticulum following laryngectomy in 11 patients, three of whom were symptomatic. Successful endoscopic CO_2 laser outcome was achieved in all three patients, with symptomatic relief.

2. Symptoms

Patients with diverticulum present with classical symptoms, and the diagnosis is therefore relatively easy. The main diagnostic symptom is regurgitation following a meal. This regurgitation is not immediate; it only appears a few hours later. The regurgitated material contains food that is still recognisable, since it has not reached the stomach and undergone digestive breakdown. Borborygmus is another classical and early symptom. A number of patients volunteer the symptom of having to take a 'second swallow', which may be described as dysphagia. Other symptoms include pharyngeal discomfort, pooling of saliva, coughing, and aspiration of food, giving rise to eventual pneumopathy and fetor. Barium swallow clinches the diagnosis, and also shows the size of the diverticulum.

3. Surgical management

Zenker's diverticuli (ZD) have traditionally been treated surgically by an external approach. Since the 1950s, endoscopic techniques have increasingly been used as a good alternative (Svendstrup *et al.*, 1992).

Patients suffering from ZD are usually in the older age group and concomitant conditions are not uncommon. Such patients may be a poor risk

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for the prolonged general anaesthesia necessary for external procedures. The choice then remains between Dohlman's procedure, a laser procedure, and stapler cutting. Laser surgery has the advantage of a shallow destruction zone, and therefore, increased accuracy.

4. Endoscopic surgical management

Endoscopic division of the common wall between the cervical oesophagus and the diverticulum is undertaken with either electrocautery (Dohlman's procedure), laser treatment, or a stapling device.

4.1. Endoscopic Dohlman's procedure

In Dohlman's procedure, the septum is grasped between the jaws of a long, insulated crocodile forceps, and diathermy is applied. The energy deposited into the septum is somewhat arbitrary. The extent of surgery is controlled by visual inspection of the blanched area. For this reason, under- or over-treatment is quite possible, although, in experienced hands, the results are more than satisfactory. Myotomy is performed with an insulated sickle knife at the conclusion of the operation. The procedure can be staged for large-sized pouches.

A variation to Dohlman's procedure was described by Mulder *et al*. (1995). Flexible endoscopic diathermy was carried out in 20 patients under local anaesthesia. There were no 'severe' intraoperative complications. Seventeen patients remained asymptomatic during a follow-up period of six months, while three died of unrelated disease. Patients complained of some sore throat postoperatively.

4.2. Endoscopic laser surgery

Several workers report the successful management of ZD using endoscopic laser surgery. Benjamin and Innocenti (1991) state that microsurgical division of the cricopharyngeus muscle in the party wall using a CO_2 laser is now an established precise, accurate, and safe procedure, providing reliable relief of symptoms with minimal risk to the patient.

Gehanno *et al*. (1999) suggest that if the diverticulum is larger than 3 cm, a two-stage procedure with the CO_2 laser excision is preferable in order to minimise complications and obtain long-term relief.

Lippert *et al*. (1999) reported the management of dysphagia in 81 patients with the CO_2 laser. Seventy patients had ZD, while 11 had diverticulum following laryngectomy. Only three patients with diverticulum had symptoms bad enough to require surgical management, and all three had a successful surgical outcome. Of the 70 cases of ZD, 90% had a successful surgical outcome. Lippert *et al.* advise a low power setting, which is similar to the diathermy rather than the ablative effect.

4.3. Transoral stapled diverticulum oesophagostomy

Peracchia *et al*. (1998) presented a detailed study on the effectiveness of transoral stapled diverticulum oesophagostomy for relieving symptoms and decreasing outflow resistance at the pharyngo-oesophageal junction in a cohort of 95 patients with ZD. Under general anaesthesia, the septum between the diverticulum and the oesophageal lumen was divided using a linear endostapler introduced through a Weerda endoscope. In most patients, two applications of the endostapler with a modified anvil were used. Operative time averaged 23 minutes.

Bates and Koay (1996) also described a technique for endoscopic diverticulotomy using a linear cutter stapling gun. They found it to be quick and bloodless. No nasogastric intubation was necessary and oral intake was possible as early as the first postoperative day. The cutter stapling gun had the additional theoretical advantage of reducing the risk of fistula formation, mediastinitis, and thermal injury to the recurrent laryngeal nerve.

5. CO_2 laser endoscopic management of Zenker's diverticulum

Inspired by the extensive experience of Van Overbeek *et al*. (1989; 1991), one of us (Remacle *et al*., 1997) adopted the CO_2 laser endoscopic technique between September 1989 and December 2000, and 62 patients (39 males and 23 females were treated for a pharyngo-oesophageal diverticulum. Their mean age was 71 years (range, 48-99 years).

Normal food intake was established in all the patients after 48 hours, except for two cases who developed a blind fistula, which closed spontaneously after a few days. In one patient, there was only partial improvement. In this case, the operation was technically difficult on account of the patient's long stature and long neck. The diverticulum was in the upper oesophagus. The diverticuloscope employed in this patient (Storz, Tuttlingen, Germany) proved to be too short, and only the proximal part of the wall could be sectioned. Since the patient's main complaint of secondary pulmonary infection had resolved completely, he declined any further surgical treatment.

Five patients were lost to follow-up and nine died from unrelated causes. Thus, a cohort of 57 patients was available for audit with a mean follow-up of 43.5 months (range, 1- 111). Fifty-one (89%) were subjectively very satisfied (no symptoms), four (7%) were fairly satisfied, and two (4%) did not obtain a satisfactory result. Of these two, one obtained only a partial success and the other required a secondary open procedure.

In two patients, intraoperative bleeding was somewhat difficult to control by coagulation, but no transfusions were required. No emphysema or mediastinitis was observed. Malignancy was not noted in any of these patients as an aetiological factor.

Follow-up with radiographic control showed complete disappearance of the diverticulum in 15 patients (Fig. 3b), while a small edge remained in 47 patients.

Five patients underwent a second CO_2 laser endoscopic procedure between six months and four years after the first procedure. One patient underwent an external procedure in another department a year after the endoscopic procedure. In the following sections, the method adopted by one of us (MR) is described in detail.

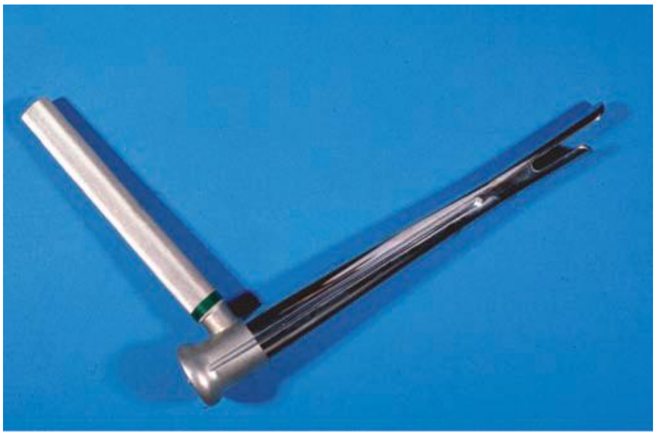

Fig. 1. Diverticuloscope designed by Van Overbeek.

5.1. Anaesthesia

The procedure is carried out under general anaesthesia and the patient is intubated. It is not necessary to protect the tube from the CO_2-laser beam because it is not in the operative field. The head of the patient must be hyperextended, as for bronchoscopy.

5.2. Instrumentation

Several types of diverticuloscope are currently available (Fig. 1). A diverticuloscope has two channels, one for carrying the light fibre, the other for smoke evacuation. The distal end has a slit on each side, thus forming a longer anterior and shorter posterior lip. When correctly positioned, the groove accommodates the septum between the lumen of the oesophagus anteriorly and the cavity of the pouch posteriorly (Fig. 2a), similar to the Dohlman's diathermy procedure.

Considerable caution is necessary when inserting the diverticuloscope since it is easy to scrape and, if forced, to traumatise the mucosa of the posterior hypopharynx. The posterior wall of the pouch is made of mucosa and submucosa, and there are no muscles that can offer any resistance and prevent perforation of the wall of the pouch. Once the anterior lip of the scope is positioned behind the cricoid, the larynx is raised while advancing the scope gently. When the pouch is of substantial size, it causes considerable pressure on the oesophagus from behind, thus pushing the opening of the oesophagus so that it lies facing almost posteriorly. In such cases, the view is tangential rather than end-on, thus increasing the difficulty even more. Gentle probing with a medium-sized boogie is of considerable help. Once the lumen is found, the scope is passed and the boogie withdrawn. Generally, the anterior lip then enters the oesophagus, while the lower lip enters the diverticulum. The diverticulo-oesophageal wall is stretched progressively in the groove between the two lips of the scope. It is not uncommon to find food debris in the fundus of the pouch. This is removed by aspiration. A thorough

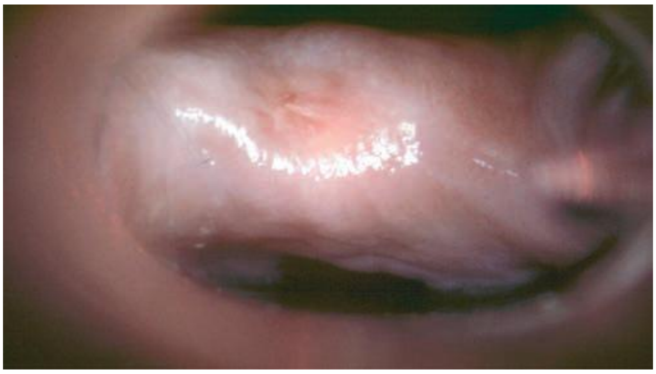

Fig. 2a. Positioning of the diverticuloscope.

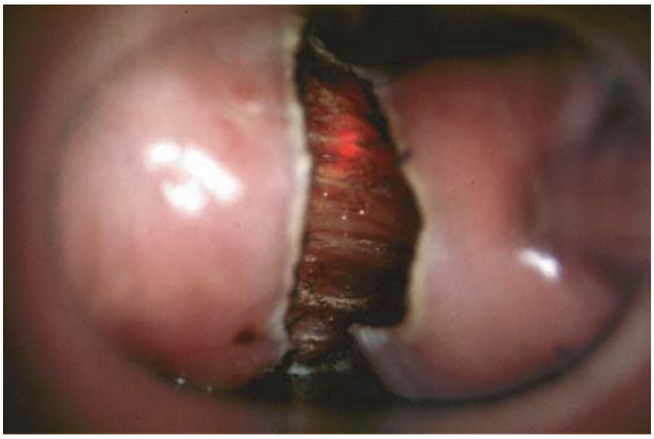

Fig. 2b. Sectioning of the diverticulo-oesophageal wall.

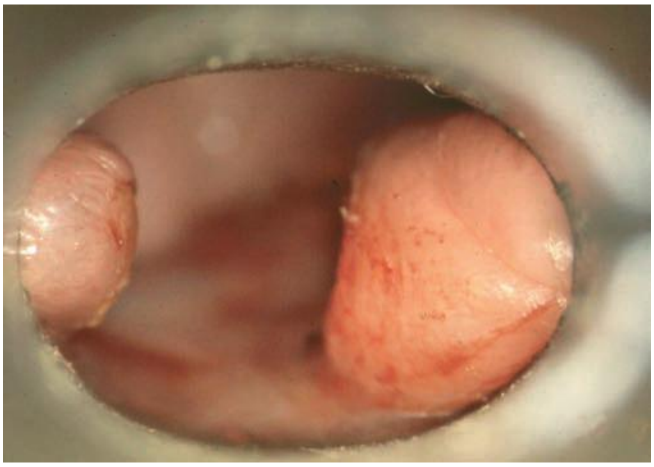

Fig. 2c. Completed section of the diverticulo-oesophageal wall. The oesophagus is clearly visible.

examination of the pouch and surrounding structures is carried out to exclude any occult carcinoma causing formation of the pouch (Arendt and Broschewitz, 1989).

The operating microscope greatly facilites localisation of the pouch and also enables any debris to be sucked out. In rare cases, a malignant lesion may be seen. The micromanipulator of the CO_2 laser is attached to the microscope in the usual manner.

5.3. The laser technique

The laser is set at a spot size of 250 µm, with a working distance of 400 mm. The power is set at 10 watts, in the continuous working mode. The Sharpulse or Acublade scanner is set at 2 mm long and 1.5 mm deep.

Wet pledgets are placed in the oesophagus and in the fundus of the pouch in order to protect the mucosa. Bleeding may occur, and this is usually controlled by suction-coagulation forceps. It is necessary to have instruments long enough to reach the fundus, not only to control any bleeding, but also to manipulate the pledgets. The usual instrumentation for laryngoscopy is of insufficient length

The incision is made in the midline of the septum. The horizontal fibres of the cricopharyngeal muscle can be seen to retract from the incision line (Fig. 2b). The excision is gently deepened by layer-bylayer vaporisation of the tissue of the septum. The object of the operation is to convert the pouch and the lumen of the oesophagus into a single cavity so that there is no blind pouch and the debris cannot collect within it (Fig. 2c). Once the sectioning is complete, the raw area is covered with fibrin glue (Tissucol, Immuno, Vienna) in order to prevent any possible leak leading to mediastinitis. A feeding tube may be passed. The average duration of the operation from anaesthesia to arousal is 30 minutes.

6. Postoperative care

'Nil by mouth' instructions are given for the first 48 hours, and hydration is maintained by intravenous fluid. Preventive antibiotic therapy is initiated at the operation and maintained for five to six days thereafter. The patient's temperature is monitored every four hours, and an X-ray is performed every day for three days in order to detect any potential mediastinitis. Normal food intake is resumed on the third

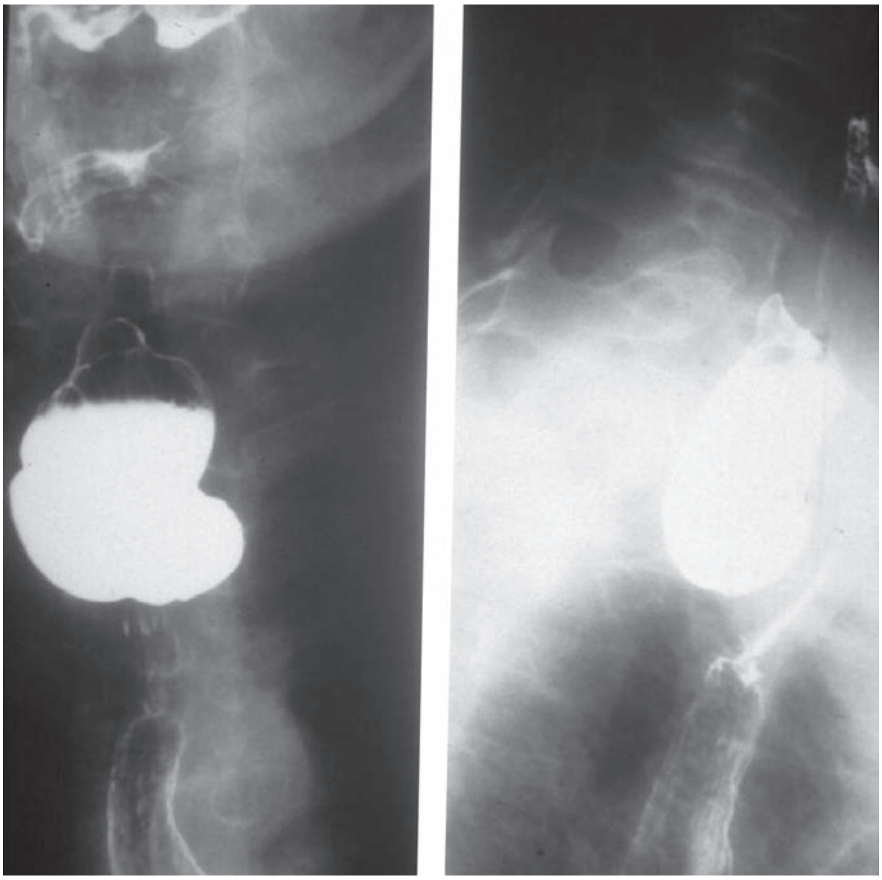

Fig. 3a. Preoperative radiography of the diverticulum.

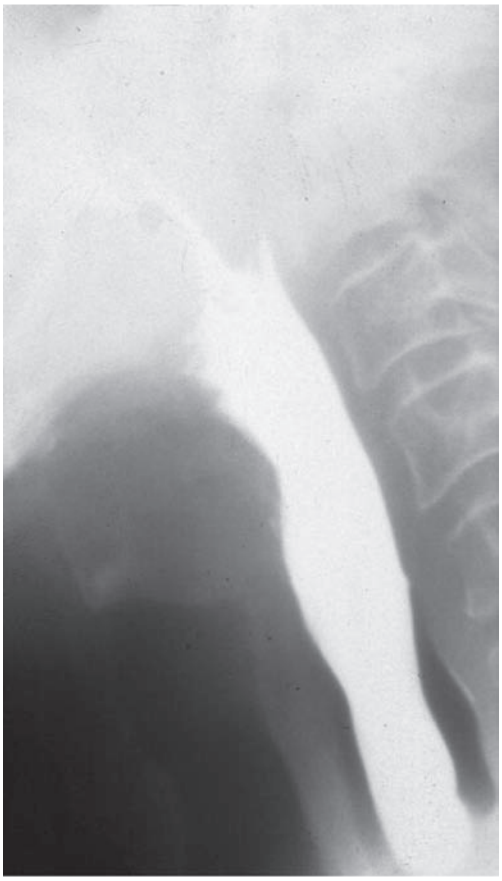

Fig. 3b. Radiography on the third postoperative day.

day, after radiographic confirmation of the absence of extravasation into the neck tissues. The patient is discharged home on the fourth or fifth day. Follow-up with radiographic control should show little or no residual diverticulum (Figs. 3a,b).

7. Postoperative complications

The postoperative complications of bleeding and subcutaneous emphysema, with or without inflammation, were reported by Nyrop *et al.* (2000).

8. Patient risks and benefits

The most obvious benefit from the procedure is cure of the various symptoms mentioned above. Other benefits include low postoperative morbidity (Wouters and Van Overbeek, 1992), and, should the need arise, the procedure can be repeated in order to improve a partial success. The success rate with the endoscopic laser procedure is comparable with that obtained with more conventional procedures, such as Dohlman's diathermy and an external operation.

In a retrospective analysis of 97 cases, Zbaren *et al.* (1999) compared the results of external versus laser endoscopic procedures (external, n = 66; endoscopic, n = 31). They found that endoscopic laser management had a lower complication rate (6.4%) when compared with the external approach (15%). In addition, the severity of the complications in the laser group was much lower than that in the external group. The average in-patient stay was eight days in the laser group compared to 11 days in the external group.

In a postoperative chart review from December 1994 to April 2009, Peretti *et al.* (2009) found one case of oesophageal fistula which resolved spontaneously within a week with antibiotics total parenteral nutrition, Three (11%) patients presented a post-operative temperature peak > 38.5°C that was resolved with anti-pyretic treatment. In another case, there was oesophageal perforation with pneumothorax which occurred during diverticulum exposure. This case therefore cannot be considered a complication resulting from CO_2 laser management of the diverticulum. Significantly, there were no cases of recurrent nerve paralysis, pharyngo-cutaneous fistula, neck emphysema, post-operative bleeding, mediastinitis or aspiration pneumonia. According to the literature and their series, the risk of mediastinitis after microendoscopic laser partial myectomy, was comparable with the external approach. Curiously, the incidence of post-operative transient fever seemed to be a common phenomenon.

Similar findings were echoed by Helmstaedter *et al.* (2009) who undertook a retrospective study of patients treated between 1983 and 2003 at their institute and found that there was one case of mediastinitis and three cases of raised temperature. A control radiography showed pharyngeal leak in three patients, They conclude that patients treated endoscopically should receive antibiotics and parenteral feeding in the postoperative period, until a routine radiograph confirms no leak.

Dauer *et al.* (2006) compared the results of the endoscopic laser-assisted procedure to those of the open-neck approach and reported a higher overall success rate for the laser group. Complications in the endoscopic group included fever (n = 2) and chest pain (n = 1); while in the open-neck group, there was one case of chest pain, one of prolonged intubation and one of fistula.

Comparing endoscopic and open neck approaches, Chang *et al.* (2004) reported no major complications (mediastinitis, pharyngocutaneous fistula, recurrent nerve paralysis, stenosis or death) in endoscopic group.

Contrary to most reviews, comparing endoscopic CO_2 laser (N=72) versus staple-assisted diverticulostomy (n=35), Verhaegen *et al.* (2011) found that patients in the staple-assisted group had a shorter hospitalization and earlier oral intake when compared with the CO_2 laser group. Postoperative fever and emphysema in the neck or mediastinum occurred more frequently in the CO_2 laser group, but this did not lead to any complications.

Welinder *et al.* (1998) compared the cost effectiveness of endoscopic laser surgery (LD, $n = 10$) versus external surgery (DE, $n = 9$) for ZD. Surgery time was reduced by 64%. Hospitalisation was shortened from a median of 16 (9-28) days in the DE group to four (0-9) days in the LD group. These factors represent a substantial costs saving when using LD compared to DE. An initial good result was seen in all patients in both groups. Symptoms recurred in 11% of the DE group (one patient), but in 20% of the LD group (two patients). Re-operation of the two patients in the LD group relieved symptoms, but one patient had to be re-operated on twice before this was achieved. Two patients in the DE group presented with complications (wound infection and pneumonia), whereas no complications were seen in the LD group.

From the above, it is clear that patient risk from endoscopic laser management is negligible, the success rate is high, and the procedure is cost-effective.

Treatment of a pharyngo-oesophageal diverticulum by the endoscopic procedure is usually criticised for two reasons: the risk of emphysema and mediastinitis arising from a breach of the oesophageal wall, and the risk of releasing malignant tumour from the fundus of the diverticulum.

Van Overbeek's (1991) success in 507 patients should suffice to refute the first point. Indeed, after the 607 operations performed on these 507 patients, only one patient died (heart failure). Eleven patients (1.8%) developed mediastinitis, and eight recovered with conservative management. There were 12 cases (1.9%) of emphysema, but this was limited to the neck and lasted only for a few days. We did not encounter any of these complications in our series. It should be remembered that these complications are not unusual in external approach procedures. Laccourreye *et al.* (1988) encountered two cases of fistula (14.5%) with mediastinitis. Wolfensberger and Simmen (1991) also reported two cases of fistula (10%) in their series. The low rate of this type of complication arising with endoscopic microsurgery is possibly due to chronic peridiverticulitis, which induces fibrosis around the diverticulum. This fibrosis becomes more important as the diverticulum enlarges.

Staplers cannot be used for small-sized pouches (Talmi *et al.*, 1989; Westmore, 1990).

The spread of cancer to the oesophagus is indeed minuscule. In fact, the incidence of cancer associated with ZD is minimal, from 0.5-1.5% (Laccourreye *et al.*, 1988). Cleansing the fundus of any food debris, and careful examination to rule out any malignancy, further reduces the possibility of potential spread (Laccourreye *et al.*, 1988). If in doubt, biopsies should be taken, and a frozen section histological examination be made prior to sectioning the diverticulo-oesophageal wall. For this purpose, it is necessary to have a sufficiently long diverticuloscope in order to be able to examine the whole length of the diverticulum.

The risk of severe haemorrhage is small (< 1%). Bleeding is controlled by aspiration-coagulation. Here again, it must be noted that adequate instruments should be available: routine laryngeal suction cannulae (25 cm) are too short and oesophageal aspirators long and unwieldy. An appropriate suction cannula (35-40 cm long) should be available.

One of the great advantages of endoscopic treatment is the speed of recovery. Van Overbeek allows his patients to take soft food as early as the day following the procedure. Empirically, we give parenteral nutrition rather than place a feeding tube on the raw area created by the division of the septum; we feel any pressure on this raw area may result in perforation leading to mediastinitis.

9. Discussion

It is generally accepted that the endoscopic management of ZD is preferable to external management. However, Sideris *et al*. (1999) advocate an external procedure for pouches greater than 5 cm in size.

Many studies have justified myotomy as an essential component in the treatment of pharyngo-oesophageal diverticula. Sideris *et al*. (1999) suggest that diverticulopexy should be added for pouches of between 1 and 4 cm and that diverticulectomy should be performed for sacs greater than 5 cm, in order to achieve maximum relief of the symptoms.

In a series of 95 patients treated with a linear endostapler introduced through a Weerda endoscope, Peracchia *et al*. (1998) found that external surgery was required in three cases (3.1%) due to difficult exposure of the common wall in two and a mucosal tear in the other. No postoperative morbidity or mortality was recorded. Oral feeding was started the following day, and the median hospital stay was three days (range, two to eight days). Five patients complained of persistent symptoms, three of whom underwent a further endosurgical operation, one of whom underwent laser treatment by means of flexible endoscopy, and another eventually required open surgery. Peracchia *et al.* (1998) maintain that an endosurgical approach to hypopharyngeal diverticula larger than 2 cm with a linear endostapler is a safe and effective method for ZD. Symptom relief, elimination of the pouch, and decreased outflow resistance at the pharyngo-oesophageal junction can be obtained without morbidity and with a short hospital stay.

Our own series of 57 patients treated with an acublade CO$_2$ laser has shown a very successful outcome in 96% of cases. It seems that CO$_2$ laser management of ZD is destined to remain a method of choice with good symptomatic relief, low morbidity, and low patient risk arising from the procedure.

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MCQ – 40. CO_2 laser endoscopic microsurgery of Zenker's pharyngo-oesophageal diverticulum

1. For CO_2 laser surgery for Zenker's diverticulum
   a. Dedicated instrumentation is advisable but not strictly necessary
   b. Dedicated instrumentation is required
   c. Lack of specific instruments such as a diverticuloscope and instruments with longer shafts than those for laryngoscope is a contraindication
   d. Long oesophageal instruments are adequate

2. A control postoperative radiograph is advisable
   a. To ensure that there is no leak in the mediastinum
   b. That there is no emphysema in the mediastinum
   c. To ensure that the septum is fully divided and there is no residual partition
   d. To ensure that there is no aspiration
   e. All of the above

3. Postoperatively, nutrition after CO_2 laser surgery should be preferably managed by
   a. By nasogastric tube
   b. By liquid oral feeds
   c. Parenterally to avoid pressure on the operating site by nasogastric tube
   d. By gastrostomy
   e. Any of the above methods

4. It is in advisable to carry out staged procedure with the CO_2 laser
   a. If the patient has co-morbidity
   b. If the septum is longer than 3 cm
   c. If it is not possible to visualise the oesophageal opening in cases of a large pouch
   d. In pseudo-pouch (after laryngectomy)
   e. All of the above

5. If the symptoms do not resolve satisfactorily after the CO_2 laser surgery,
   a. The patient should be advised external procedure
   b. A repeat CO_2 laser procedure can be undertaken
   c. There is a greater chance of complications for repeat CO_2 laser procedure
   d. A fibre guided laser such as the KTP laser should be used for a better palpation and direct contact strike

6. One of the aetiological factors for the formation of the pouch is malignancy. In such cases, the risk of spreading the cancer in to the mediastinum is
   a. A contraindication for CO_2 laser surgery for Zenker's diverticulum
   b. Miniscule since the incidence of malignancy is less than 1% and therefore the CO_2 laser surgery is not contraindicated
   c. Minimised by carefully removing all the food particles to inspect the fundus of the pouch prior to undertaking surgery
   d. By taking biopsies in doubtful cases for frozen section

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Chapter 41

Basic science in photodynamic therapy in multidisciplinary oncological care

C. Hopper

1. Photodynamic therapy: an overview

PDT is based on initial sensitisation of the target tissue with an agent with photo-sensitising properties. The agent selectively accumulates in target tissue. The subsequent light delivery to the target tissue results in cellular destruction by a non-free radical oxidative process. The photochemical reaction following PDT is non-thermal.

Photodynamic therapy can be delivered under local or general anaesthesia and the delivery method can include surface illumination or interstitial application. The selective uptake and retention of a local or systemically administered photosensitiser in pathological tissue is an important factor in PDT. When tumour : normal tissue photo-differentiation has reached an optimum, the photosensitiser is activated by *non-thermal* light of the appropriate wavelength. This results either in the production of oxygen free radicals (type-I mechanism) or the formation of intracellular singlet oxygen (type-II mechanism), which causes tumour cell death by intracellular oxygenation and vascular shutdown mechanisms (Hopper, 2000; Jerjes *et al*., 2007; Jerjes *et al*., 2009).

The photosensitising agents exhibit an inherently low systematic toxicity and, significantly, have a remarkably little effect on connective tissues, thus resulting in healing with minimum scarring. When used in hollow organs such as the airways, the luminal integrity is retained without fibrous tissue formation. Major blood vessels maintain their mechanical integrity as collagen and elastin are largely spared. This therapy can be applied in conjunction with any of the conventional treatment modalities (*i.e.*, surgery, radiotherapy or chemotherapy). The treatment can be repeated as often as necessary since it has no cumulative toxicity (Hopper, 2000; Jerjes *et al*., 2007; 2009).

1.1. Photosensitisers

At the time of writing, three first-generation photosensitisers have been approved by regulatory authorities. These are: Photofrin (porfimer sodium), 5-ALA (5-aminolaevulanic acid) and Verteporfin (BPD, benzoporphyrin derivative). Photofrin was the first photosensitiser to have received approval, and it is now licensed for the use in the oesophagus, lung, stomach, cervix and bladder. 5-ALA is a naturally occurring precursor in the heme biosynthetic pathway, and, to date, it has received approval only for non-malignant and pre-malignant disorders. It is converted to the endogenous photosensitiser protoporphyrin IX, which then can be activated by red, green and even blue light.

Development and introduction of newer photosensitisers and light delivery systems have substantially reduced treatment times and residual photosensitivity, while increasing the range of effective depth (*i.e.*, necrosis and peri-lesional inflammation), (Hopper, 2000, Jerjes *et al*., 2007; 2009). A potent second-generation photosensitiser, Foscan (temoporfin; meta-tetrahydroxyphenyl chlorine) has been approved for treatment of advanced head and neck cancer. It is activated at 652 nm, with a residual photosensitivity of only two weeks, but can reach up to six weeks (Hopper, 2000; Jerjes *et al*., 2007; 2009).

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1.2. Mode of action

Photosensitisers are incorporated directly into cellular membranes, but they do not seem to accumulate within cell nuclei. The direct cytotoxic activity and microvascular damage contribute to the destruction of tumour cells, which is manifest as tissue necrosis and inflammatory swelling. The necrotic tissue eventually sloughs away (or is resorbed), followed by normal healing and re-epitheliasation (Jerjes *et al*., 2010).

1.3. Route of Administration

Most photosensitisers are administered systemically, although some can be applied topically (*e.g.*, for skin pathology). The depth of effect that can be achieved depends on the photosensitiser used. Systemic administration of the photosensitiser leads to a period of unwanted residual photosensitivity that must be managed until the drug is eliminated (Hopper, 2000; Jerjes *et al*., 2007; 2009).

1.4. Treatment protocol – m-THPC

Compared to Photofrin and ALA, meso-TetrahydroxyPhenyl Chlorine (mTHPC-Foscan; second-generation) is a potent photo-sensitiser for cancer management. It is commonly used in advanced head and neck cancer. The maximum absorption peaks at 652 nm with a drug dose of 0.15 mg/kg, and a DLI (drug light interval) of 96 hours. When illuminating, the fluence is set at 10-20 J/cm^2 and the fluence rate is standardized at 100 mW/cm^2.

1.4.1. I/V administration

mTHPC 0.15 mg/kg is administered intravenously in the mid-cubital vein 96 hours prior to treatment to allow maximum accumulation of the photosensitiser in the target tissue. The patients are kept in a dim-lit 'side room' as light exposure in an open ward can risk systemic photosensitisation.

1.4.2. Illumination

Treatment time is related to the absorption of light by the photosensitiser and also the efficiency of transfer of light energy to oxygen. Light-emitting diodes and xenon lamp sources are commonly used for dermatological application, but lasers are the most convenient and controllable light source (Hopper, 2000; Jerjes *et al*., 2007; 2009).

On day 4, each patient undergoes examination under anaesthesia (EUA) of the oral cavity. The tumour size and volume is re-assessed, followed by shielding of the macroscopically normally surrounding tissue, using 'thick' thermal black wax. A margin beyond the dysplasia or tumour mass is not shielded and subsequently illuminated with the pathology. The objective is to achieve a macroscopic clearance of 0.2-0.3 cm in dysplasia and 0.5-1.0 cm in cancer.

A single-channel 652-nm diode laser is used for illumination. The laser light delivery fibre, with a core diameter of 400 μm, is held with its tip at a distance of five cm from the tumour mass. The laser light is delivered with a spot size of three cm in diameter and 20 J per site (200 seconds per treatment). Further areas are illuminated when indicated. Iso-illumination treatment plan is carefully implemented and supervised by a senior physicist to ensure adequate light delivery to all suspect areas with minimal overlapping between the fields of treatment using a grid system.

The position of the pulse oximeter is changed every 30 minutes during illumination, since red light (660 nm) can activate the photochemical reaction leading to skin burn and nail damage.

At the conclusion of the treatment, ten ml of 0.5% bupivacaine is administered locally to control the postoperative pain. No epinephrine is included as this can cause vasoconstriction, and compromise the treatment outcome.

1.5. Post-treatment management

Following the treatment, it is expected that patients will experience pain and swelling which may compromise breathing and swallowing. Therefore, when indicated, nasopharyngeal tubes for breathing and nasogastric tubes for feeding are inserted. Pain usually peaks at 48-72 hours. Patients are discharged from hospital care 7-10 days post-PDT.

1.5.1. Pain

Special PDT pain protocols are followed. The regime of pain control involves a fentanyl transdermal patch 72 HR 12 mcg/hr with morphine sulphate (immediate release) as needed for breakthrough pain. Dose-escalating medication or patient controlled analgesia (PCA) is implemented when indicated. Usually, different specialist centres have different PDT pain control protocols depending on experience and the areas treated. It is essential to highlight the fact that patient's pain response varies with PDT.

1.5.2. Systemic photosensitivity

Systemic photosensitivity presents a problem as the skin continues to be sensitive to light for up to 12 weeks. Every patient is instructed on the need to avoid direct sun exposure for up to two weeks after injection and was given light exposure guidelines. Gradual light re-exposure at an incremental rate of 100 lux per day is implemented. Some patients may fail to achieve a gradual re-exposure to sun light. In these patients, first- to third-degree skin burn can occur when exposed to direct sun light for the first time after three to four weeks post-treatment.

2. Literature review

Photodynamic therapy is widely used in oncology both for primary curative treatment and for palliation/salvage therapy. A brief description of some applications is outlined below.

2.1. Head-and-neck tumours

Multiple studies have showed that head and neck cancer responds favourably to PDT, particularly as primary and as an alternative treatment modality for early oral and laryngeal cancers. In a cohort of 276 patients with early carcinomas of the oral cavity and larynx, Biel (2007) reported a cure rate of 91% and 94%, respectively. A phase I-II study recruited 45 patients for 'last hope' salvage with interstitial PDT therapy, all patients had untreatable head and neck cancer. The outcome assessment was for safety and efficacy of interstitial PDT. Nine patients achieved a complete response. Five are alive and disease-free 10-60 months later. Symptomatic relief (mainly from bleeding, pain or tumour bulk affecting function) was achieved in a further 24 patients. The median survival was 16 months for the 33 responders, but only two months for the 12 non-responders (Lou *et al.*, 2004). Airway problems and peri-orbital swelling is reported when treating oropharyngeal tumours. The management is by nasopharyngeal intubation and steroids.

2.2. Barrett's oesophagus

Barrett's oesophagus, a precursor of oseophageal adenocarcinoma, has been shown to respond favourably to the photochemical reaction induced by PDT. A commonly reported problem is residual islands when treating with topical photosensitisers. A five-year randomised trial of patients with Barrett's esophagus and high-grade dysplasia demonstrated that Photofrin-PDT was a clinically and statistically effective therapy in producing long-term ablation and reducing the potential impact on cancer, compared with omeprazole (Overholt *et al.*, 2007). PDT appears to potentially cure approximately one-third of superficial esophageal cancers and provide a local control of high-grade dysplasia in a similar subset of patients (Keeley *et al.*, 2007). Complications following PDT included stenosis, fistulas and perforation. Their incidence is reduced by using 180° or 240° windowed light distributors, and by partial shielding with inflatable balloon when illuminating, with flexible cylindrical diffusers.

2.3. Lung cancer

PDT can be a very effective palliative agent in lung cancer. It has been shown to reduce symptoms of dyspnoea in patients with completely or partially obstructing endobronchial small cell lung cancer (Usuda *et al.*, 2006). PDT can be curative when applied to early non-small cell lung cancer. Corti *et al.*, (2007) reported on the efficacy of PDT for early inoperable or recurrent non-small-cell lung cancer in 40 patients. Twelve cases, staged as T1N0M0, were inoperable due to co-morbidity. Further 28 had recurrent *in situ* carcinoma. PDT obtained a 72% complete response rate and the mean overall survival was 75.59 months. Reported side effects were cough, expectoration of necrotic debris and dyspnea for a few days after PDT. Serious or fatal haemorrhage was occasionally reported.

Other successful applications of PDT are reported in the treatment of superficial bladder cancer, basal-cell carcinoma (BCC), Bowen's disease, cholangiocarcinoma, pituitary tumours, glioblastoama, prostate cancer, cervical intraepithelial neoplasia, Kaposi sarcoma, retinoblastoma, malignant human lymphocytes and many others (Hopper, 2000; Brown *et al.*, 2004; Triesscheijn *et al.*, 2006; Wainwright, 2008). Discussion on these conditions is beyond the scope of this chapter.

3. Clinical applications

Photodynamic therapy (PDT) remains an attractive therapeutic option in oncology. In principle, administration of the photosensitiser, followed by light application to the target 'lesional' area leads to a photochemical reaction. Several hours later, selective damage to the target tissue ensues. The efficacy of the treatment depends on the type and the concentration of the photosensitiser, light dose, dose rate, the availability of oxygen and cellular localization. Several photosensitisers are currently being tested for better specificity for target tissue (*i.e.*, tumour), (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008).

3.1. Photosensitisers

Two generations of photosensitisers are used in oncology. Profimer Sodium (Photofrin-first generation) is commonly used in Barrett's high grade dysplasia, and cervical, gastric, oesophageal, endobronchial and papillary bladder cancers. 5-aminolevulinic acid (ALA), a natural haeme precursor, has been successfully applied in basal cell carcinoma (BCC), actinic keratosis (AK) and oral dysplasia. Foscan (mTHPC-meso-tetrahydroxyphenyl chlorin, second generation), a much more potent photosensitiser for cancer treatment, when compared to Photofrin and ALA, is commonly used in head-and-neck cancer. Third generation photosensitisers (tin ethyl etiopurpurin [SnET2], mono-L-aspartyl chlorin e6 [Npe6], benzoporphyrin derivative [BPD] and lutetium texaphyrin [Lu-Tex]) are already in clinical trials; initial results showed better tumour specificity and shorter generalised photosensitivity (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008).

3.2. Mechanism

Various processes are involved in affecting the destruction of the tumour mass. Direct targeting of the superficial tumour leads to initiation of necrosis or apoptosis via singlet oxygen generated by the photochemical reaction. Targeting the tumour vasculature results in avascular necrosis, followed by immune response against the residual pathological process (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008) (Fig. 1).

3.3. Method of delivery

Method of delivery of the laser energy depends upon the site and the size of the tumour mass. Superficial tumours can be successfully approached through surface illumination. The penetration can extend up to 1cm deep, depending upon the sensitiser used (*e.g.*, mTHPC). Furthermore, bulky superficial tumours can be initially debulked, followed by photochemical reaction directed in the base (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008).

Deep invading tumours are relatively inaccessible and impose limitation to widespread use of PDT. For such tumours, special grids are made and needles are inserted in to the tumour and guided under the imaging control of Ultrasound (US), Magnetic Resonance Imaging (MRI) or Computerised Tomography (CT). When in position, fibres are fed through them

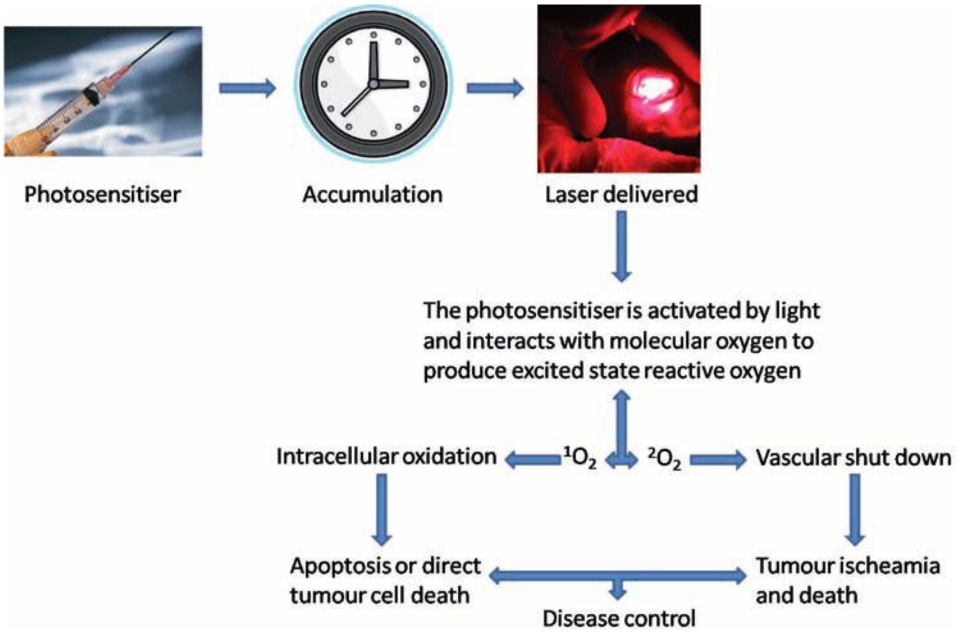
Photosensitiser
Accumulation
Laser delivered
The photosensitiser is activated by light and interacts with molecular oxygen to produce excited state reactive oxygen
Intracellular oxidation
$^1O_2$
$^2O_2$
Vascular shut down
Apoptosis or direct tumour cell death
Tumour ischeamia and death
Disease control

Fig. 1. Principle of photodynamic therapy.

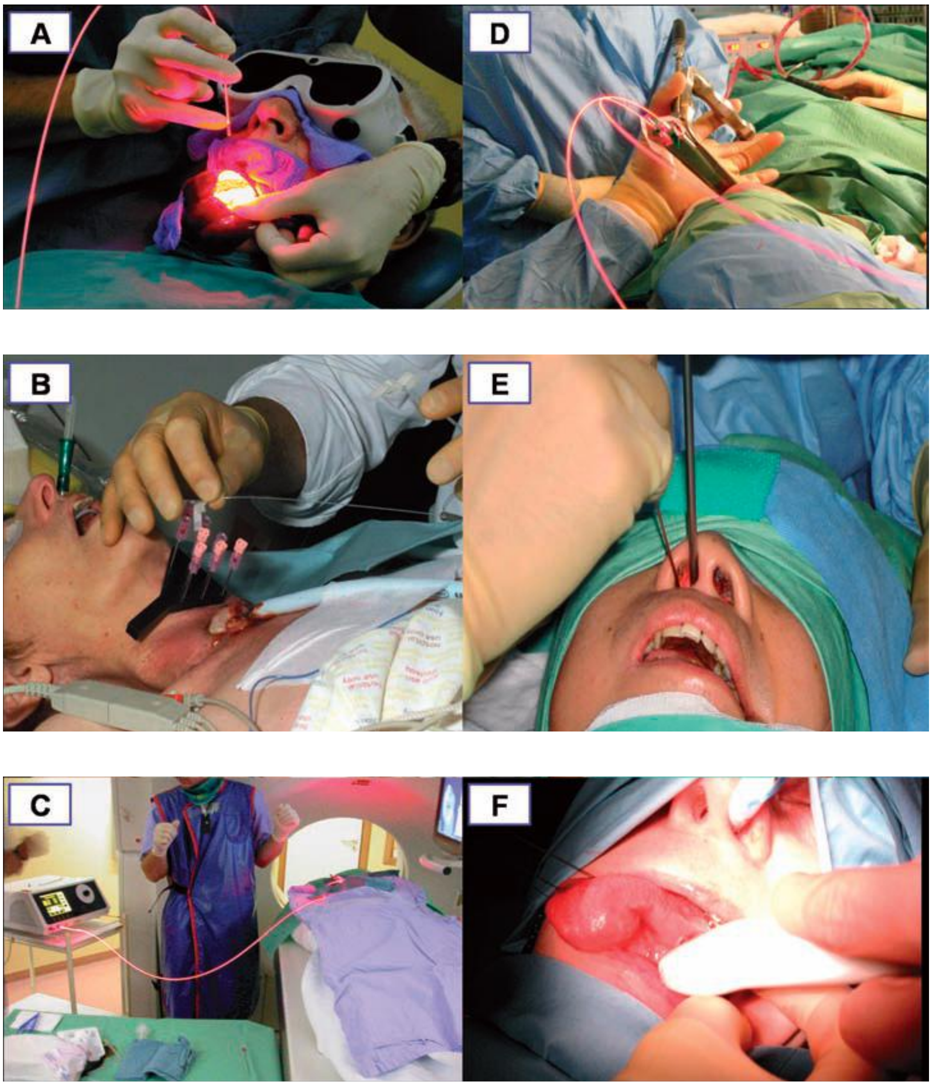

Fig. 2. Mode of light delivery. A. Surface illumination. B. Prefabricated grid guided. C. Magnetic resonance imaging guided. D. Laryngoscope guided. E. Nasendoscope guided. F. Ultrasound guided.

and pushed until their ends protrude beyond the needles for a few millimetres to allow maximum illumination. The energy is delivered by a pull-back technique, to cover the entire tumour bulk (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007, Wainwright, 2008) (Fig. 2).

More recently, intraoperative guidance of the needles has allowed more accurate placement. This is followed by illumination and treatment by the relevant specialty department (*i e*., US, MRI, CT, flexible nasoendoscopy, laryngoscopy), (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008).

4. Post-treatment course

When the photosensitiser is activated, by light, it is expected that the photochemical reaction will continue for few hours, followed by cellular death for up to six to eight weeks. During this period, pain and the photosensitivity represent the primary problems.

4.1. Pain

Pain is usually controlled by NSAIDs, but the patient might need opiates, especially when the delivery of light is by illumination. Usually each specialist centre has its own PDT pain-control protocol, depending on experience and the areas treated.

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Some photosensisers cause a prolonged period of pain, lasting in excess of 10-13 weeks.

4.2. Photosensitivity

Continuing photosensitivity represents another problem as the skin continues to be sensitive to light for up to eight weeks. Some patients fail to achieve a gradual re-exposure to sun light, and any inadvertent exposure may cause first or second degree burn (Fig. 3). Adjacent area of skin, near the injection site, sometimes, fail to achieve a gradual re-exposure to sun light and as a result patients develop first- or second-degree skin burn, when they are exposed for the first time to direct sun light after three to four weeks of treatment (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008).

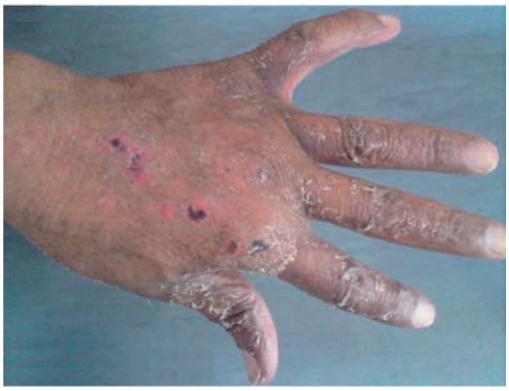

Fig. 3. Accidental sun exposure two weeks after photodynamic therapy led to skin burn of the dorsal hand associated with ulceration and peeling of the skin.

5. Benefit and risk issues

It is not uncommon for the adjacent skin to appear both macroscopically and microscopically ‘normal’ and yet, it can undergo necrosis and/or apoptosis with unfavourable outcome. Such incidents are minimised by using special probes or by shielding the non targeted tissue. Of course, ideally, a highly selective sensitiser should obviate any need to protect adjacent tissue, but at the time of writing, such photosensitisers are not yet available.

Healing usually occurs with almost no scarring and the procedure can be repeated with little cumulative toxicity. Likewise the tissue architecture is also preserved, providing matrix for regeneration of normal tissue.

Previous studies have reported successful treatment of primary tumours. Palliation or salvage therapy of advanced tumours to reduce bulk, restore function, control pain and bleeding, can also be achieved. Photochemical reaction can be induced in single or multiple lymph nodes under image-guidance but this can be sometimes difficult to perform when dealing with a complex lymphatic chain (*e.g*., in the head and neck). Difficulties are also encountered when the tumour starts to metastasise through the lymphatic system. In such case it is not feasible to induce a therapeutic photochemical reaction in a large area of the body (*i.e*., neck, groin, axilla). Alternative therapies (*i.e*., ablative surgery, radiotherapy, chemotherapy) at this stage can also lead to severe problems which can affect form and function. Thus, no single treatment has been proven to be more successful than the other. However, by combining more than one modality, a degree of improvement in morbidity and/or mortality can be achieved (Hopper, 2000; Brown *et al*., 2004; Triesscheijn *et al*., 2006; Jerjes, 2007; Wainwright, 2008).

6. Discussion

Photodynamic therapy is a minimally invasive treatment with great promise in malignant disease. The excellent cosmetic outcome makes it valuable for skin cancer and its ability to preserve form and function makes it an excellent choice for cancerous lesions of the head, neck, and oral cavity. With endoscopic delivery of light to hollow structures, PDT has been successful in the treatment of early oesophageal cancer and lung cancer. PDT has a significant role in palliative therapy; it can reduce tumour size, control pain and stop bleeding in advanced cancers.

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MCQ – 41. Basic science in photodynamic therapy in multidisciplinary oncological care

1. In photodynamic therapy, the tissue interaction depends on
    a. The staging of the tumour
    b. The type of photosensitiser
    c. The type of laser light
    d. The availability of oxygen
    e. All of the above

2. In Head and Neck cancer the most commonly used photosensitizer is
    a. Foscan (mTHPC, mesotetrahydroxyphenyl chlorin, second generation)
    b. 5-aminolevulinic acid (ALA)
    c. Profimer Sodium (Photofrin-first generation)
    d. All of the above

3. The mechanism of the action of photodynamic therapy
    a. Involves administration of a chemical which is toxic to the neoplastic malignant tissue and its blood supply – similar to chemotherapy
    b. Involves administration of a chemical which has propensity to concentrate in mitotic tissue
    c. Involves use of laser to activate the tissue so that toxicity of the chemical is potentiated
    d. Involves breakdown of the chemical with a specific wavelength laser light, which releases singlet oxygen, toxic to the mitotic tissue
    e. All of the above

4. Photodynamic therapy is useful for
    a. Deep and large tumours which take up the chemical administered intravenously
    b. Superficial tumours, 1 cm deep, which can be easily accessed by laser light
    c. Bulky tumours which can be accessed by insertion of several needles to provide channel for insertion of fibres which take laser light to the tumour
    d. Mucosal lesions such as Barrett's oesophagus
    e. Anaplastic large tumours with necrotic centres

5. Photodynamic therapy
    a. The destructive effects are both immediate as well as delayed
    b. It destroys the tissue directly due to the cytotoxic action of singlet Oxygen
    c. It also continues to destroy the tissue due to avascular necrosis for 6 – 8 weeks post-treatment
    d. For the destructive action to continue, it is necessary to deliver the light again within 6 - 8 weeks without further administration of the photosensitiser
    e. All of the above

6. During the post-treatment period
    a. Pain is a major issue
    b. The recovery is painless
    c. The patient remains sensitised to light for 6 – 8 weeks
    d. Patients are allowed to go in the light provided they take precautions
    e. Exposure to sunlight may result in first or second degree burn in some patients

7. The photodynamic therapy
    a. Has a cumulative effect and therefore no further treatment is advised for 3 - 6 months
    b. Has no cumulative effect
    c. Produces excessive scarring in some patients.
    d. Preserves without scar formation and thus functional outcome is excellent
    e. Preserves matrix which provide scaffolding for tissue regeneration, thus restoring form

8. Photodynamic therapy
    a. Is curative in some cases
    b. Is palliative in other cases
    c. Reduces bulk
    d. Controls bleeding
    e. All of the above

9. In photodynamic therapy
    a. The main concern is photosensitivity
    b. Significant pain remains an issue
    c. High cost is a consideration to its wide use
    d. Special centres are advisable
    e. Its use is not yet recognised as the ‘forth’ modality after surgery, radiotherapy and chemotherapy
    f. All of the above

Chapter 42

Photodynamic therapy in the management of superficial oral pathology

W. Jerjes and C. Hopper

1. Introduction

Photodynamic therapy (PDT) is a minimally invasive modality successfully targeting premalignant and malignant disorders in the head and neck, gastrointestinal tract, lungs and skin with greatly reduced morbidity and disfigurement. The technique is simple, can usually be carried out in outpatient clinics, and is highly acceptable to patients. The role of photodynamic therapy in the management of potentially malignant oral disorders and early oral cancer is discussed in this chapter.

2. Potentially malignant oral disorders

Potentially malignant oral disorders, previously called potentially malignant lesions or conditions, are identified by exclusion of clinical characteristics of other white and red lesions, and histological confirmation. Leukoplakia and erythroplakia represent the majority of these disorders. Other, less common pathologies include oral lichen planus, oral submucous fibrosis, actinic cheilitis, xeroderma pigmentosum, Fanconi's anaemia and immunodeficiency (*e.g.*, immunosuppressive agents, human immunodeficiency virus and chronic graft versus host disease) (van der Waal, 2009; Mehanna *et al.*, 2009; van der Waal, 2010).

The worldwide prevalence of oral leukoplakia is about 2%. Chronic smokers and drinkers are more likely to develop this disorder. There is conflicting evidence linking human papilloma virus to oral leukoplakia (van der Waal, 2009; Mehanna *et al.*, 2009; van der Waal, 2010). The prevalence of oral erythroplakia, in selected studies, is less than 1%. Risk factors are similar to the ones for oral leukoplakia (van der Waal, 2009; Mehanna *et al.*, 2009; van der Waal, 2010).

Clinically, oral leukoplakia may be homogeneous or non-homogeneous (erythroleukoplakia); the latter can be either speckled or nodular in appearance. Verrucous leukoplakia, another variant of non-homogenous leukoplakia, has higher tendency to malignant transformation.

2.1. Diagnosis of potentially malignant oral disorders

The current gold standard for identifying dysplastic changes is histopathology to identify architectural changes and cellular atypia. Epithelial precursor lesions in this area involve squamous hyperplasia, mild, moderate, or severe dysplasia, and carcinoma *in situ*. Several authorities have identified substantial interobserver and intraobserver variation in the assessment of oral dysplastic lesions and their categorisation (van der Waal, 2009; Mehanna *et al.*, 2009; van der Waal, 2010).

2.2. The management of potentially malignant oral disorders

Oral dysplastic lesions carry a significant and substantial risk of malignant transformation. A systematic review by Mehanna *et al.* (2009) suggested a

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figure of 12.3%, which was more likely to increase with severe dysplasia and carcinoma *in situ*. Also it was postulated that, although surgical excision appears to reduce the risk of transformation by more than a half, it is not altogether eliminated. Unfortunately, the authors did not clearly link the role of smoking and drinking to malignant transformation.

The management of these oral potentially malignant disorders is not well defined. However, centres around the world seem to agree on the basic principles. These include reducing risk/exposure factors, complete removal of the lesion and follow-up by continuous monitoring, which can be for lifetime. The indications for active intervention are therapeutic, such as presence of symptoms and/or preventive, to pre-empt potential malignant transformation. Lesion removal is usually employed via surgical excision with cold instrumentation, laser surgery or cryosurgery. Additional modality of photodynamic therapy has been introduced in the past two decades, and is playing an increasingly active role in the management of these lesions. The use of retinoids and mouthwash with attenuated adenovirus also seems to have a role in the management (van der Waal, 2009; Mehanna *et al*., 2009; van der Waal, 2010).

3. Oral Cancer

Cancer of the oral cavity ranks sixth amongst the most common cancers in the world. Unfortunately, the incidence continues to rise, and despite the recent advances in surgery and radiotherapy, survival rate remains moderate (Bagan and Scully, 2008; Warnakulasuriya, 2009; Jerjes *et al*., 2010).

3.1. Prevalence of oral squamous cell carcinoma

Oral squamous cell carcinoma (OSCC) affects more males than females with a ratio of 1.5:1 in the fifth or sixth decade of their life. However, there is an increasing trend of oral cancer affecting young people under the age of 45 years, accounting to about 6% of all age groups. Higher incidence of oral squamous cell carcinoma has been identified in South and Southeast Asia, Latin America, and the Caribbean, and in some parts of the western world, especially in France. The incidence of oral cancer has also been found to be higher in ethnic minorities in other developed countries (Bagan and Scully, 2008; Warnakulasuriya, 2009; Jerjes *et al*., 2010).

3.2. Tumour site

The most common oral sites to be affected with squamous cell carcinoma include the lateral border of the tongue, the ventral tongue and floor of mouth. In the Asian population, the buccal mucosa is commonly affected due to betel quid/tobacco chewing habits (Bagan and Scully, 2008; Warnakulasuriya, 2009; Jerjes *et al*., 2010).

3.3. The tumour size

The tumour size is one of the most important factors affecting prognosis. This usually influences the clinician's options to decide between ablative surgery, radiotherapy, chemotherapy, photodynamic therapy or just proceed to palliative care which could include a combination of any of the above therapies. Also, it is well documented that increased tumour size is related to local and regional disease spread, higher recurrence rates and poor prognosis (Noguchi *et al*., 2002; Garzino-Demo, 2006; Shah and Gil, 2009; Mazeron *et al*., 2009; Specenier *et al*., 2009).

3.4. Loco-regional spread

Loco-regional spread to the cervical chain adversely influences treatment options and worsens the outcome. Several factors have been known to influence local and regional tumour spread to the lymphatics. These include the primary site, tumour volume, double DNA aneuploidy, poorly differentiated tumours, infiltrating-type invasive front and perineural and peri/endovascular invasion. Distant tumour spread occurs most commonly in uncontrolled local and regional disease and N-stage disease (Noguchi *et al*., 2002; Garzino-Demo, 2006; Shah and Gil, 2009; Mazeron *et al*., 2009; Specenier *et al*., 2009).

3.5. Histological grading

The influence of the histological grading as a prognostic factor in oral squamous cell carcinoma has been documented in several studies and found to be a significant predictor of local and regional failure as well as tumour recurrence. Positive close tumour margins are usually associated with high risk of local recurrence and have a negative effect on survival (Noguchi *et al*., 2002; Garzino-Demo, 2006; Shah and Gil, 2009; Mazeron *et al*., 2009; Specenier *et al*., 2009).

The following paragraphs cover management option with the new non-invasive modality of photodynamic therapy.

4. Emerging role of PDT in the management of neoplastic aero-digestive pathology – literature review

Photodynamic therapy (PDT) is a minimally invasive modality, successfully targeting premalignant and malignant disorders in the head and neck region. Unlike other treatment options, it is associated with greatly reduced morbidity and disfigurement. The technique is simple and can usually be carried out in outpatient clinics, with a high patient-tolerance rate.

4.1. Premalignant lesions (field cancerisation)

Patients with a head-and-neck squamous cell carcinoma (HNSCC) often develop multiple (pre)malignant lesions. This finding led to the concept of field cancerisation (FC), the term first coined by Slaughter *et al*. in 1953. It refers to histologically abnormal epithelium adjacent to tumour tissue within the aerodigestive region. The majority of the mucosal alterations appear to be related to the exposure to alcohol and/or tobacco.

FC may induce CA, CIS or dysplasia which can be recognised histologically. Despite adequate resection, the remaining ‘field’, although grossly normal, is more susceptible to future CA, frequently labelled as second primaries or local recurrences.

The concept of multiple patches of premalignant disease has been extended to the oropharynx, oesophagus, stomach, lung, colon, anus, cervix, bladder and skin.

The management of patients with premalignant lesions of the oral mucosa in ‘field cancerisation’, with multicentric foci of invasion, presents a considerable problem for the surgeon. Radiotherapy is not always feasible since it can only be given once and is associated with significant local morbidity.

Grant *et al*. (1993) reported the use of PDT to treat 11 patients with ‘field cancerisation’ occurring in the oral cavity. Six patients had multiple primary cancers and five had single primary tumours. Six to eight weeks later, treated areas in ten of the 11 patients showed a complete response to PDT. One patient had areas of residual leukoplakia; while two patients developed further areas of leukoplakia or erythroplakia within 12 months. However, no patient has had evidence of recurrent invasive carcinoma in the treated areas.

In another study (Fan *et al*., 1996), 18 patients were treated with ALA-PDT for histologically proven premalignant and malignant lesions of the mouth. There was a consistent epithelial necrosis with excellent healing in all cases. This study found that ALA-PDT is a simple and effective way to manage these patients.

More recently, Tsai *et al*. (2004) developed a light-emitting diode (LED) array combined with topical 5-aminolevulinic acid (ALA) for photodynamic therapy (PDT) and evaluated its effectiveness for the treatment of potentially malignant oral disorders. The clinical part of the study included a total of 33 oral lesions which included leukoplakia, verrucous hyperplasia, erythroleukoplakia, and verrucous carcinoma. Using the LED light source, a total of 24 leukoplakia lesions were treated with ALA-PDT. The result was a complete response in three, a partial response in nine, and no response in 12 lesions. In the five lesions of verrucous hyperplasia, complete responses were found in four and partial response in the remaining patient. Partial responses were found in the two erythroleukoplakia and one verrucous carcinoma lesions. They concluded that ALA-PDT is effective for pre-malignant disorders.

An interesting study was reported by Rigual *et al*. (2009), assessing the response of dysplasia, carcinoma *in situ*, and T1 carcinoma of the oral cavity and larynx to photodynamic therapy with porfimer sodium. Responses were evaluated at 1 week and at one month and then at three-month intervals thereafter. Twenty-four patients had a complete response, one had a partial response, and one had no response. Three patients with oral dysplasia with an initial complete response experienced recurrence *within* the treatment field. Temporary morbidities included oedema, pain, hoarseness, and skin phototoxicity. All patients who showed no response, a partial response, or recurrence after an initial complete response underwent salvage treatment. The authors concluded that porfimer sodium-PDT is an effective treatment option, with no permanent sequelae.

Biel (2007) reported his series of 276 patients with early carcinomas of the oral cavity and larynx. His cure rates with a single treatment for early laryngeal and oral cancers were 91% and 94%, respectively. He postulated that PDT is an effective primary and alternative treatment modality for early oral cavity and laryngeal cancers.

An earlier study by Hopper *et al*. (2004) on 121 early oral squamous cell carcinoma patients treated by mTHPC-PDT showed a complete response in 85% of protocol-compliant patients (97 of 114 patients). A complete response was maintained in 85% of responders at one year and in 77% at two years. One- and two-year actuarial survival rates were 89% and 75%, respectively. In the opinion of the investigators, tumour clearance was accompanied by excellent cosmetic outcome.

5. Authors' experience – Potentially malignant oral disorders

In a prospective study carried out at the Department of Surgery of University College London Medical School, a total of 147 consecutive patients with potentially malignant oral disorders were treated with surface illumination PDT, using 5-ALA or mTHPC as the photosensitiser. The average age was 53 ± 8.9 years. Ex- and current lifelong smokers formed 84.4% of the recruited patients, while people who currently smoked and drank, formed 38.1% (56 patients) of the cohort.

5.1. Lesions

The most frequent sites for the lesions were lateral border of tongue, floor of mouth and retromolar area. Homogenous leukoplakias were identified in 55 patients, non-homogenous leukoplakia in 73 patients, whereas 19 patients had erythroplakia. Erythroplakia was mainly identified in heavy lifelong smokers. Moderate dysplasia was identified in 33 patients while 63 patients had severe dysplasia. Thirty-two patients had a histopathological diagnosis of carcinoma *in situ*.

5.2. Study parameters

Study parameters consisted of clinical and histopathological features, rate of recurrence and malignant transformation. The patients were followed up for a mean of 7.3 years.

5.3. Study outcome

The patients' recovery was uneventful and no complications were noted.

Complete response was identified in 119/147 patients (81%). The rate of recurrence following PDT was approximately 11.6%. Malignant transformation was observed in 11 patients (7.5%), in the tongue, floor of mouth and retromolar area. Recurrence and malignant transformation was mainly identified in erythroplakias and non-homogenous leukoplakias (Fig. 1).

The final outcome of the cohort showed that 11 patients (7.5%) suffered from progressive disease, five (3.4%) had stable disease and 12 (8.2%) were considered partially responsive to the therapy. These results provided conclusive evidence that 5-ALA-PDT and/or mTHPC-PDT offer an effective alternative treatment for potentially malignant oral disorders.

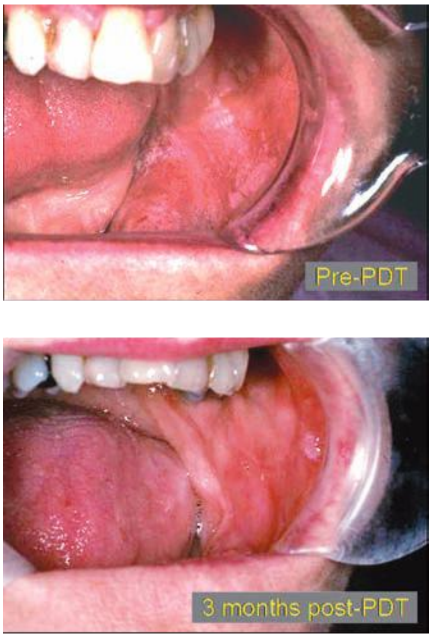

Fig. 1. PDT in the management of potentially malignant oral disorders. Top image: oral dysplasia prior to PDT illumination. Bottom image: macroscopically healthy oral tissues three months post-PDT.

6. Authors' experience – oral cancer

In another prospective study carried out at authors' centre, a cohort of 38 patients suffering from T1/T2 N0 oral cancer were subjected to mTHPC-photodynamic therapy and followed up for a minimum of five years. Clinico-pathological parameters, recurrence, survival and disease progression were assessed.

The mean age at the first initial diagnosis of OSCC was 58.0 years. Common clinical presentation was an ulcer in the tongue, floor of mouth or buccal mucosa. Current/ex-smokers represented 89.5% of the cohort; while current/ex-drinkers were 86.8%. Clinically 29 patients had T1 disease while none had

T2 disease. Histopathological diagnosis showed 12 patients with well differentiated SCC, 16 moderately-differentiated and ten with poorly-differentiated cancer. All patient were discussed in a multi-disciplinary meeting and, subsequently, underwent mTHPC-PDT and were followed-up postoperatively.

PDT was repeated in three to six months period following the first round when residual tumour was identified in the primary site. Nine patients received one round of PDT, 22 patients received two rounds and seven patients had three rounds. All the primary tumour sites responded favourably to the treatment (Fig. 2).

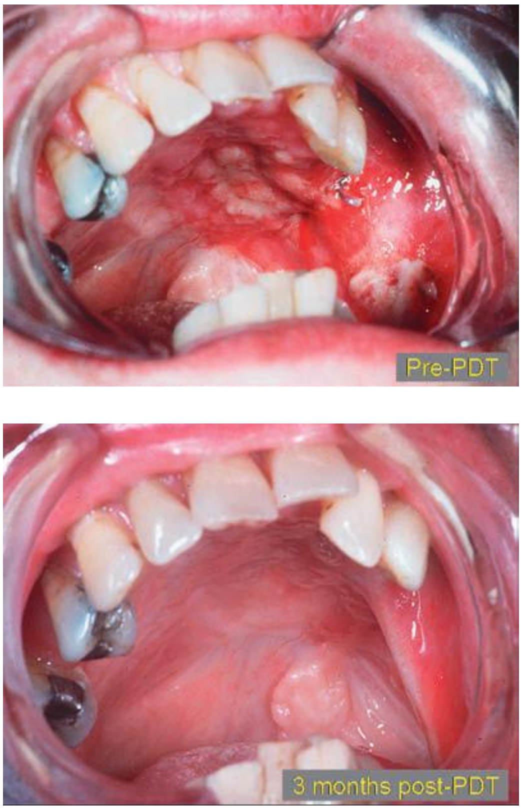

Fig. 2. PDT in the management of superficial oral cancer. Top image: field change disease (SCC) of the oral cavity prior to PDT illumination. Bottom image: histologically proven healthy oral tissues three months post PDT.

6.1. Study outcome

No disease progression was identified in any patient. At five-year post-PDT review, 26/38 patients showed completely normal clinical appearance of their oral mucosa in the primary tumour site. Recent surgical biopsies from the study cohort showed that 17 had normal mucosa, five with hyperkeratinisation, ten with dysplastic changes and six showed recurrent SCC. The overall recurrence was 15.8% and the five-year survival was 84.2%. Death from loco-regional and distant disease spread was identified in three patients.

Overall recurrence was 15.8% and the five-year survival was 84.2%. Death from loco-regional and distant disease spread occurred in three patients. The recurrence group comprised six patients. The mean age of first diagnosis of the recurrence group was 59.3 years.

Most common presentation of recurrence was an ulcer involving the buccal mucosa or retromolar area, identified in current/ex-smokers and current/ex-drinkers. The surgical margins in this group were also evaluated following laser or surgical excision, neck dissection and reconstruction. Based on our experience, mTHPC-photodynamic therapy is a successful modality in the treatment of T1/T2 N0 OSCC. The treatment might be repeated to treat any residual disease. PDT is comparable modality to other traditional interventions, but with less morbidity.

7. Benefit and risk issue

7.1. The advantages

There is little current published data assessing the use of PDT in the treatment of early tumours (TNM stage: T1/T2 N0) of the head and neck. The advantages of the use of PDT compared to radiotherapy include its potential for multiple administration and the ability to treat a higher resolution tumour volume when combined with ultrasound guidance for interstitial administration. It is particularly useful for application in cases of ‘field effect’ of mucosal cancerisation, without jeopardising the potential to use other therapeutic modalities (further surgery, interstitial PDT or radiotherapy).

Previous studies (Hopper 2000; Jerjes *et al*., 2007; Jerjes *et al*., 2009) have reported successful treatment of primary head-and-neck tumours. Advanced tumours can also be treated for salvage/palliative therapy, with the aim to reduce the tumour bulk to improve function. Bleeding and pain can be reduced to a more manageable level.

7.2. Adverse effects

7.2.1. Pain and oedema

The notable adverse events in the immediate post treatment phase include pain and swelling. Pain was experienced at some stage following PDT by all patients. In most cases pain commenced 24-48 hours following completion of treatment and lasted for several days (Grant *et al*., 1997). In some instances oral opiate analgesia was necessary. The use of a local analgesic and anti-inflammatory spray prior to meals was found to be useful.

Pain was present in 82% of PDT-treated patients while swelling was limited to only 10%. Pain was generally mild to moderate in severity and commonly persisted for two to four weeks, decreasing in intensity as the healing progressed. The pain usually required short-term treatment with nonsteroidal anti-inflammatory drugs (NSAIDs), in addition to opiates. The reporting of pain was mirrored by a temporary rise in white blood cell levels, which followed the induction of tissue necrosis and the onset of acute and chronic inflammatory responses (Hopper *et al*., 2004).

7.2.2. Residual systemic photosensitization

The major side effect of PDT is residual systemic photosensitization, which lasts for several days or weeks depending on the type of photosensitiser used. This is caused by minor concentrations of the photosensitiser in the skin and may lead to oedema, sunburn, or even superficial skin necrosis when the skin is exposed to bright light.

7.3. Limitations

7.3.1. Administration of photosensitiser

So far, 5-aminolevulinic acid (5-ALA) is the only photosensitiser that can be applied topically; all others have to be given intravenously. The advantage of topically applied ALA is the complete lack of systemic photosensitivity and therefore, ALA-treated patients do not have to avoid exposure to light following treatment. The major disadvantage of a topically applied photosensitiser is the shallow treatment depth of only one to two mm that can be obtained. Therefore only very superficial lesions of less than one mm can be treated successfully with topical application (Grant *et al*., 1997; Hopper, 2000; Hopper *et al*., 2004; Jerjes *et al*., 2007; Jerjes *et al*., 2009).

7.3.2. A need for specialised equipment

The disadvantage to the technology is that it involves some specialised equipment and training. There is a large capital outlay. However, this is easily negated by the potential benefits to the patient (quicker administration, better cosmetic result and quality of life) when compared to some alternative conventional treatment schedules (Grant *et al*., 1997; Hopper, 2000; Hopper *et al*., 2004; Jerjes *et al*., 2007; Jerjes *et al*., 2009).

7.3.3. Loco-regional spread

Difficulties arise when the tumour starts to metastasise through the lymphatic chain. In such cases it is not feasible to induce a therapeutic photochemical reaction in a whole area of the body (*i.e.*, neck, groin, axilla). A photochemical reaction can be induced in single or multiple lymph nodes under image-guidance but this can be sometimes difficult to perform when dealing with a complex lymphatic map as in the neck. Alternative therapies (*i.e.*, ablative surgery, radiotherapy, chemotherapy) at this stage can lead to severe problems which can affect form and function (Grant *et al*., 1997; Hopper, 2000; Hopper *et al*., 2004; Jerjes *et al*., 2007; Jerjes *et al*., 2009).

8. Discussion

Photodynamic therapy is an appropriate stand alone intervention, or as an adjunct to surgery. It is minimally invasive and can be applied repeatedly at the same site with no cumulative toxicity. It is also a viable option where radiotherapy is contraindicated. This modality causes tissue destruction via the interaction between oxygen (in tumour tissue), light (of a specific wavelength) and a photosensitising drug. The photosensitiser is administered intravenously or topically. It is selectively retained in the target tissues. The nature of the tissue dictates the interval for maximum accumulation. Laser light can then be directed at the tumour following a sufficient drug-light interval, thus activating the drug and initiating the cold (non-thermal) photochemical reaction.

So far, photodynamic therapy (also known as the fourth modality, the first three being surgery, radiotherapy and chemotherapy) has been successfully used in the management of a variety of pathological lesions from different anatomical sites. These include the head and neck, brain, lungs, hepatobiliary tree and other gastrointestinal pathology, skin, gynaecological conditions and in vascular anomalies.

In summary, conventional management of premalignant and malignant changes in the mouth, often widespread, are frequently excised conventionally or with the laser. Photodynamic therapy (PDT) offers yet another option, on its own or in combination with other modalities. Interaction of light with previously administered photosensitizing agent leads to a local tissue necrosis of target tissue. There is no cumulative toxicity and the healing is with remarkably little scarring.

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MCQ – 42. Photodynamic therapy in the management of superficial oral pathology

1. Epithelial precursor lesions for potentially malignant oral lesions are
   a. Hyperplasia
   b. Benign leukoplakia
   c. Mild, moderate or severe dysplasia
   d. Carcinoma in situ
   e. Erythroplakia

2. The management of epithelial precursor lesions consist of
   a. Removal of risk factor/s
   b. Excision
   c. Radiotherapy
   d. Wait and watch policy
   e. Life time monitoring

3. Field cancerisation
   a. Means regional spread of disease
   b. Means multifocal disease
   c. Means despite adequate resection, the remaining 'field', although grossly normal, is more susceptible to future CA, frequently labelled as second primaries or local recurrences
   d. Means histologically abnormal epithelium adjacent to tumour tissue within the aerodigestive region
   e. Means presence of premalignant tissue in the adjacent mucosa

4. Photodynamic therapy for oral cancer
   a. Offers multiple treatment potential
   b. Treatment is spread over a number of weeks, similar to radiotherapy
   c. Excellent for field cancerisation
   d. Field cancerisation is a contraindication
   e. Tumour debulking and restoration of function is achievable

5. Post-treatment pain is an unwanted feature of photodynamic therapy
   a. It can be avoided by reducing dosage of photosensitiser
   b. It is much less if post-treatment light exposure is avoided
   c. It is experienced by every patient, 24 – 48 hours post-treatment and lasts for 2 – 4 weeks
   d. It is caused by photosensitisers
   e. It is mirrored by increased white cell count and is thus due to acute and chronic inflammatory reaction to tissue necrosis

6. Post-treatment oedema is an unwanted feature of photodynamic therapy
   a. It is experienced by every patient, 24 – 48 hours post-treatment and lasts for 2 – 4 weeks
   b. It is much less common sequel compared to pain
   c. It does not require any treatment
   d. It needs active management in case it jeopardises the integrity of food and airway passages
   e. It is caused by photosensitisers if exposure to light occurs after the treatment

7. Topical application of 5-ALA
   a. Does not result in generalised skin sensitivity
   b. It is necessary to avoid light exposure post-treatment at least for a week

   c. It penetrates deep up to 1 cm and is thus useful for small tumours not exceeding 1 cm in diameter
   d. It is useful for many skin lesions
   e. All of the above

8. Photodynamic therapy
   a. Requires a specialised equipment
   b. Skilled and trained team
   c. Intensive care facility
   d. A large capital outlay
   e. A Regional centre

Chapter 43

The role of photodynamic therapy in the management of deep head-and-neck pathologies

W. Jerjes, T. Upile and C. Hopper

1. Introduction

Incidence of head-and-neck cancer remains high and tends to increase with age. In the UK, 85% of the patients are above the age of 50 years. Recently, however, there has been an increase of incidence amongst young persons of both genders due to human papilloma virus-driven cancers (Chapter 9) (Jerjes *et al*., 2010). Squamous cell carcinoma remains the most common carcinoma in the head and neck region; with oral and oropharyngeal carcinomas ranked the sixth most common cancers in the world. Despite evolution in management, the overall five-year survival rate continues to be slightly above 50% (Bagan and Scully, 2008; Warnakulasuriya, 2009).

The overall prognosis is governed by the primary tumour size and nodal involvement. High-risk tumours (T3/T4 with nodal disease) have a poorer outcome as they tend to resist conventional treatment modalities and are acknowledged to have a high recurrence rate. Moreover, the cumulative effects of tobacco, betel nut quid and alcohol decrease the survival rate (Noguchi *et al*,. 2002; Garzino-Demo *et al*., 2006).

2. Conventional modalities

2.1. Surgery

Currently, the gold standard of management is surgery. Radiotherapy has been proposed as neoadjuvant and adjuvant with chemotherapy (Shah, 2009). Photodynamic therapy (PDT) is moving towards becoming the '*fourth modality'*; favourable results have been achieved in managing advanced tumours of the head and neck, using PDT.

With surgery, resection of the primary tumour is advocated with dissection and removal of the ipsilateral cervical lymphatic chain, when indicated. Reconstruction of the defect can be by locoregional repair or by distant free tissue transfer. The radiotherapy, combined with use of free tissue transfer has improved survival from 40% to 70% (Vaughan, 2009).

2.2. Radiotherapy

Radiotherapy plays a key role in the management of early-stage, locally advanced head and neck cancers, either alone or more frequently, combined with surgery and/or chemotherapy. Radiation is applied postoperatively close to, or directly, to the involved surgical margins to maintain local control (Mazeron *et al*., 2009).

2.3. Chemotherapy

The role of chemotherapy in the management of head-and-neck cancer continues to evolve. Locoregional advanced squamous cell carcinoma can respond to chemotherapy, as an induction or palliative treatment, with irradiation. The current most favoured regimens for induction chemotherapy include cisplatin/infusional 5-fluorouracil/docetaxel (Specenier and Vermorken, 2009). Recent trials have shown that the use of concurrent single-agent

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chemoradiotherapy (cisplatin) led to a clear survival benefit of 11% (Bernier *et al.*, 2004; Cooper *et al.*, 2004).

3. Photodynamic therapy

PDT remains an elegant therapeutic option in interventional oncology. In principle, light application to the target 'lesional' area leads to a photochemical reaction; this is usually induced several hours after the administration of the photosensitiser and leads to selective injury to the target tissue. The efficacy of the treatment depends on the type and the concentration of the photosensitiser, light dose, dose rate, the availability of oxygen and cellular localisation. The treatment can be repeated with little cumulative toxicity. A number of photosensitisers are currently being tested for enhanced specificity for target tissue (*i.e.*, tumour), (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*; 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

3.1. Light delivery

Light delivery modus operandi depends up on tumour parameters. Treatment of surface or superficial lesions is carried out through surface illumination. This is a very successful method and the depth of effect can reach up to 1cm when using certain photosensitisers (*e.g.*, mTHPC). Superficial bulky tumours can be surgically reduced and the photochemical reaction applied to the base to eradicate tumour margins (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*; 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

Difficulty arises when treating deep invading tumours. Here, special needles need to be inserted into the target tissue. Fibres are then fed through the needles to deliver the light. Initial management involves preoperative imaging to determine size and depth, followed by reconstruction of multi-hole grids to allow needle insertion and fibre loading, enabling light delivery to the deep margins. Fibres need to protrude by two to three mm from the needle tip to allow maximal tissue illumination. Then, each single unit (needle and fibre) is pulled back to ensure light delivery to the whole tumour volume in two-dimensional application therapy (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*; 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

Intra-operative image-guided needle insertion into the tumour mass has enabled more accurate identification of the tumour centre and periphery. Here, a three-dimensional application therapy is enabled. This is usually aided by a specialist in head and neck interventional radiology. To date, guiding modalities include two-dimensional ultrasound, magnetic resonance imaging, computed tomography, nasoendoscopy, laryngoscopy and bronchoscopy (Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

3.2. Photochemical reaction

When the photosensitiser is activated by light, it is expected that the photochemical reaction will last for a few hours. However, the subsequent tumour death may continue to show macroscopic changes up to six to eight weeks after light delivery. This usually appears as a layer or mass of necrotic tissue separated from surrounding living tissue, followed by tissue regeneration. Healing usually occurs with minimal scarring. Architecture is preserved, providing a matrix for the regeneration of normal tissue (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*, 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

4. Review of literature

4.1. Magnetic resonance system for Interstitial PDT for advanced head-and-neck tumours

Jäger *et al.* (2005) reported the use of an open interventional magnetic resonance system to guide interstitial PDT for advanced head and neck tumours. They found this technique to be accurate and safe. Initial results are encouraging, with minimal procedural morbidity, successful palliation of symptoms and prolongation of expected survival time.

4.2. Ultrasound guided Interstitial PDT for advanced head and neck tumours

In a recent study, Jerjes *et al.* (2009) prospectively evaluated the outcome after ultrasound-guided interstitial PDT of deep-seated advanced pathologies. End-point outcome parameters were based on patients' evaluation of quality of life, along with clinical and radiological evaluation. Sixty-eight patients were recruited for various deep-seated pathologies involving the head and neck region; and upper and lower limbs. All patients underwent interstitial PDT under general anaesthesia. Photosensitising agent m-tetrahydroxyphenylchlorin (mTHPC) was used at a dose of 0.15 mg/kg. After treatment, patients were followed-up for a mean of seven months. Three patients who presented with visual problems immediately after treatment, reported improvement. Fourteen out of seventeen reported improvement in breathing.

Improvement in swallowing was reported by 25/30 patients. Speaking improvement was evident in 16/22 patients. Reduction in the disfigurement caused by their pathology was reported by 33/44. Five patients who had impeded limb function reported some degree of improvement.

A clinical assessment showed that half of the patients had a 'good response' to the treatment and a third reported a 'moderate response'. Two patients were free of disease. Post operative radiological assessment was compared six weeks later, with the baseline. It showed a minimal response in 18 patients, a moderate response in 23 patients and a significant response in 11 patients. In 13 patients, there was stable pathology although there was no change in size.

4.3. PDT for palliation

Photodynamic therapy was also proved to be a successful palliative modality in the treatment of advanced tongue base carcinoma. Twenty-one consecutive patients with advanced tongue-base cancer were treated using mTHPC (Foscan®)-PDT. Following treatment, patients were followed up for a mean of 36 months (Min 20, Max 45). Nine of the 11 patients who presented with breathing problems reported improvement after treatment. Also, 19 of the 21 patients reported improvement in swallowing. Improvement of speech was reported by 11 of 13 patients.

Clinical assessment showed that more than half of the patients had 'good response' to the treatment whereas about a third reported 'moderate response'. Radiological assessment, comparing imaging to the baseline 6-week post-PDT, showed 'stable' pathology. There was no change in size of the tumour mass in four patients, minimal response in seven patients, moderate response in six patients and significant response in two patients. Eight patients died; out of these, four died due to loco-regional disease (Jerjes *et al*., unpublished data).

5. Our method and protocol

5.1. Preliminaries

The patient undergoes counselling at the head and neck multidisciplinary team meeting. mTHPC is usually given at a dose of 0.15 mg/kg intravenously into the midcubital vein 96 hrs before treatment. This would allow the agent to accumulate in the pathological area, which would increase affectivity. Patients are usually kept in a side room (with a dim light) to avoid systemic photosensitisation.

5.2. Intra-operative assessment

Intra-operatively, an ultrasound (EMP 1100 with high resolution) probe is used to examine the pathological tissue (centre and periphery). The main aim here is to determine tumour volume, depth, invasion of vascular structures, hollow organs or hard tissue.

5.3. Insertion of needles and fibres

Following assessment 18 gauge 70 mm long spinal needles are inserted under ultrasound guidance into the pathological tissue. Great care is taken to ensure that the needles are inserted parallel to each other with 1cm distance in between. If the treatment is close to a major blood vessel, a safety distance of one cm between the needle and the vessel is implemented to avoid any possible risk of the vessel wall rupture, in case it is infiltrated with the tumour (Figs. 1-3).

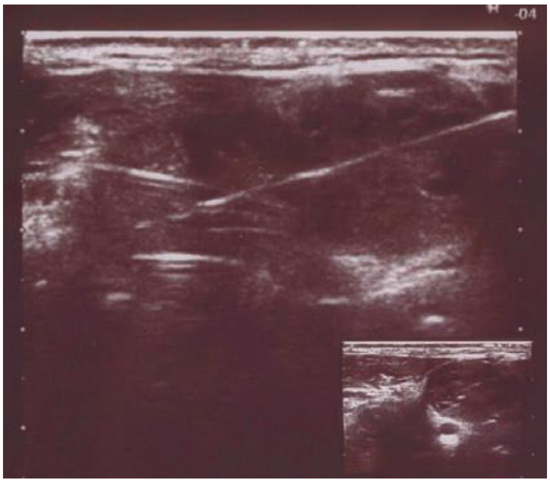

Fig. 1. Ultrasound image showing needle insertion in bilateral tongue base carcinoma followed by insertion of polished tip optical fibre. The patient also had necrotic cervical lymph node (inset) treated at the same time.

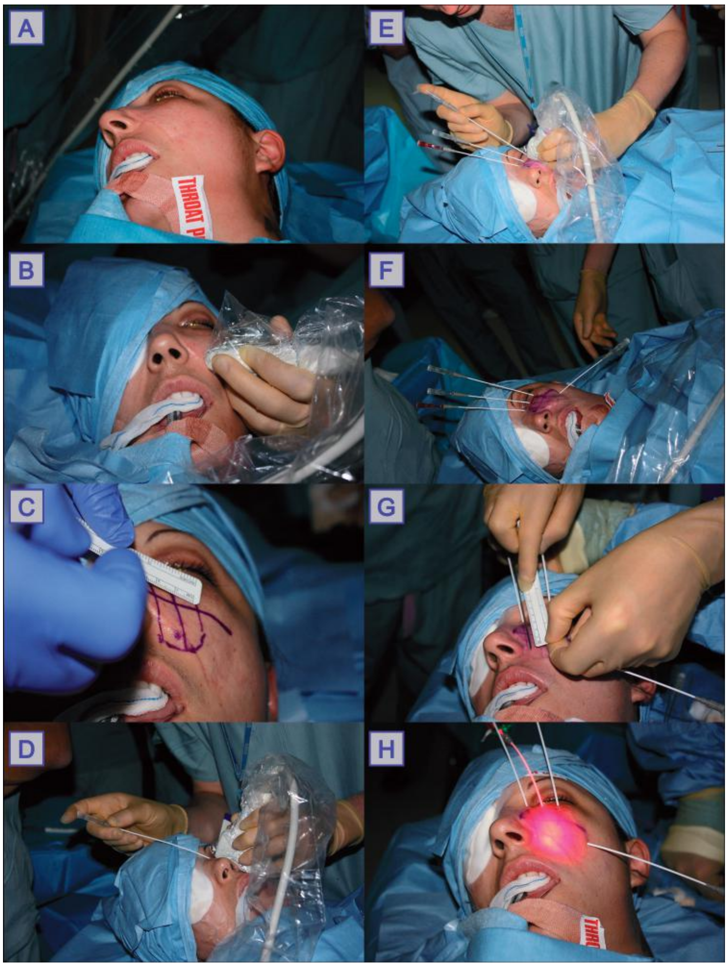

Fig. 2. US-guided interstitial photodynamic therapy of vascular tumour of the left infraorbital region. A. Patient draped, prepped and eye shield applied; B. Intraoperative ultrasound scanning of the centre and periphery of the lesions; C. Marking the path for needle insertion; D. First needle insertion under US-guidance; E. Further needles inserted; F. Complete needle insertion to ensure coverage of the whole lesion width and depth; G. Measuring needle length inside the tissue to ensure that the tip is not too close to the skin surface which can lead to necrosis, this was followed by optical diffuser fibres insertion; H. Light delivered to the diseased tissue.

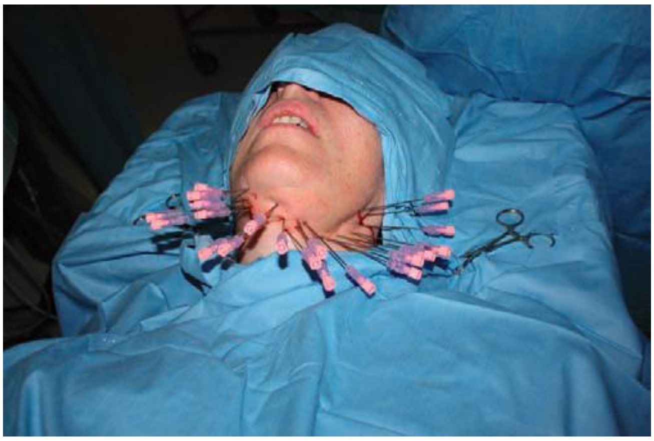

Fig. 3. Needle insertion under US-guidance in a patient with bilateral tongue base and floor of mouth carcinoma with multiple reactive cervical lymphnodes.

Histopathological specimens acquired from previous studies in authors' centre showed that illumination from one bare tip fibre results in a one-cm diameter pathological tissue necrosis. Hence, fibres are one cm apart from each other to cover all the volume of the suspect area. Any residual pathological tissue in between the necrotic areas is also expected to die from damage after oxygen deprivation. However, overlapping treatment fields are clinically insignificant, as 200 secs illumination of the area is adequate to activate the non-thermal photochemical process. Thick tumours are treated with one cm pull back at each time to ensure illumination of the whole tumour volume.

5.4. Laser illumination

A four-channel 652-nm diode laser is used for illumination. Bare polished tip laser light delivery fibres with a core diameter of 400 µm are introduced via spinal needles into the tumour. The fibres are allowed to protrude by two to three mm from the needle tip into tissue to ensure maximal tissue illumination. Light is then delivered from the fibres to the target tissue at 20 J/cm^2 per site (200 secs/treatment). Each bare tip fibre delivers an output power of ~0.5W.

Adjacent macroscopically normal tissue can become photosensitised and undergo necrosis or apoptosis, causing an unfavourable outcome (*e.g.*, ulceration of the mucosa, necrosis of the skin). The optimal way of reducing these effects is by ensuring that the light does not illuminate any adjacent areas, either by using special probes or by shielding the adjacent tissues (*i.e.*, by using surgical drapes to shield the skin or thick black wax to shield the oral mucosa) (Grant *et al*., 1993; Hopper, 2000; Hopper *et al*.; 2004; Lou *et al*., 2004; Jäger *et al*., 2005; Jerjes *et al*., 2009). Diffuser fibres are used when treating vascular tumours, together with the bare polished tip fibres. The structure of the vascular tumours allows maximal tissue illumination when using these types of fibre.

An iso-illumination treatment plan is carefully implemented and supervised by a senior physicist to ensure adequate light delivery to all suspect areas with minimal overlapping between the fields of treatment using a grid system. No additional measurements are made with regard to the distribution of the light fluence rate, the optical properties, the drug concentration, and the tissue oxygenation for PDT, as these factors had already been quantified in previous studies carried out in our centre.

The position of the pulse oximeter is changed every 30 min to avoid any skin burn or nail damage that would result from photochemical reaction by the red light (660 nm).

6. Post-illumination management

Postoperatively, gradual light re-exposure and airway and pain control are implemented., Patients are discharged from hospital care three to seven days postoperatively. Six weeks postoperatively, restaging, magnetic resonance imaging or computed tomography views are acquired to assess outcome (Figs. 4-5).

Patients are asked to report on the outcome of their therapy if there is any improvement, no change or worsening of symptoms. They are asked to complete a questionnaire, developed for patients receiving PDT of the head and neck (modified from the

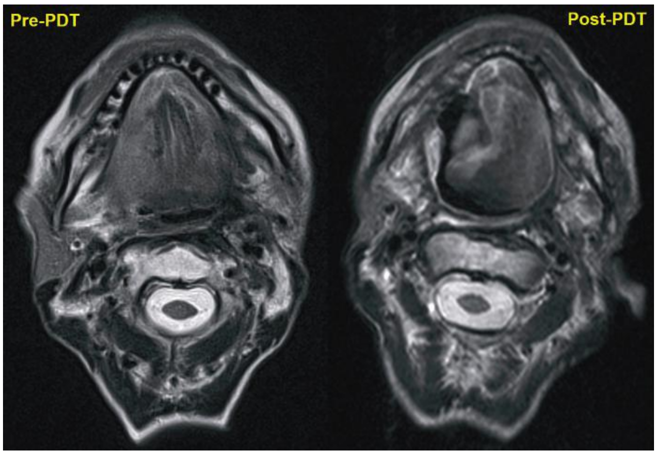

Fig. 4. Axial MRI scanning of SCC of the posterio-lateral tongue. Left: pre-PDT; Right: post-PDT showing extensive necrosis of the tumour area.

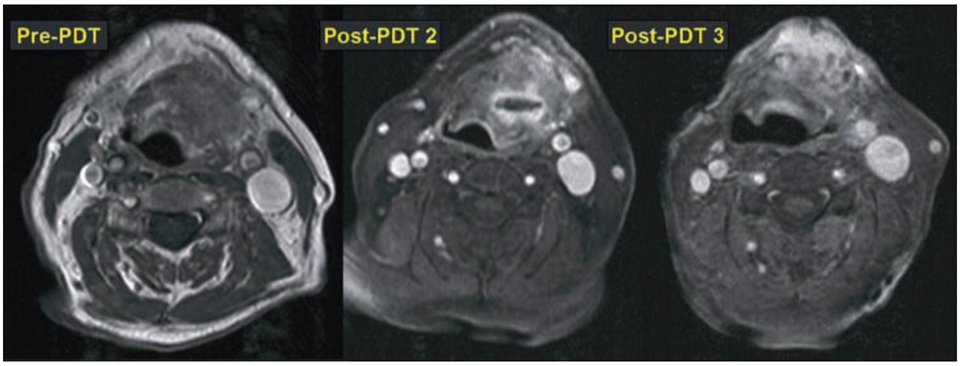

Fig. 5. Axial MRI scanning of chondrosarcoma of the neck. Left: pre-PDT; Middle: response after two rounds of PDT showing central necrosis and good response on the T2-wight scan; Right: after the third round of PDT showing significant tumour shrinkage and good response on the T2-weight scan with increase in airway patency.

University of Washington Quality of Life Questionnaire for head-and-neck cancer patients).

A postoperative clinical assessment is reported by the treating clinician at the first post-PDT review (at ~ 4-6 weeks). A postoperative radiological assessment is reported by the same interventional radiologist.

7. Benefit and risk issue

Intra-operative image-guided needle insertion into the tumour mass has enabled more accurate identification of the tumour centre and periphery.

7.1. Post-therapy pain

Post-therapy (after PDT), patients experience a considerable amount of pain in the treated area. The pain usually peaks at 48-72 hrs postoperatively. Special PDT pain protocol is followed. The standard regimen involves a fentanyl transdermal patch 72 HR 12 μg/h. Morphine sulphate (immediate release) is needed for breakthrough pain. Dose escalating the patient's own pain medication or prescribing patient-controlled analgesics is implemented when indicated. Usually different specialist centres have different PDT pain control protocols depending on experience and the areas treated (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*; 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

7.2. Photosensitivity

Photosensitivity represents a problem as the skin continues to be sensitive to light for up to anything between eight and 13 weeks with some photosensitisers. Gradual light re-exposure at an incremental rate of 100 lux per day is implemented. Every patient is instructed on the need to avoid direct sun exposure for up to two weeks after injection and is given light exposure guidelines. Sometimes patients fail to achieve a gradual re-exposure to sunlight and as a result they develop first or even second-degree skin burn, when they are exposed for the first time to direct sun light after three to four weeks of treatment. Also, the skin over the injection site (especially the arm area) is more sensitive to light and skin burn has been reported to occur up to ten weeks after the photosensitisation in this area (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*; 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009)(Fig. 6).

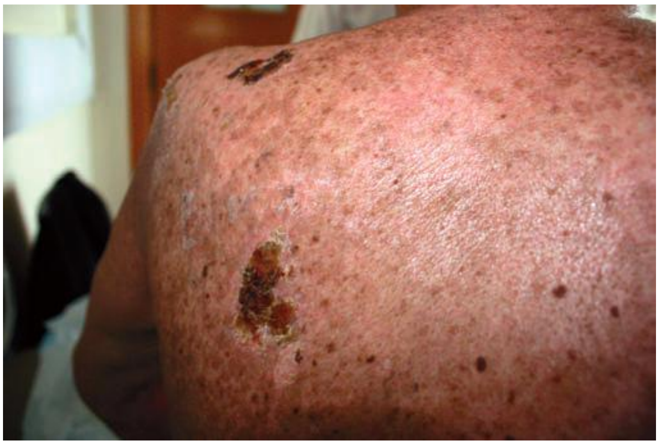

Fig. 6. Healing of third-degree skin burn following inadvertent sun exposure.

7.3. Airway compromise

Airway control is a priority, as airway compromise can occur as a result of the local inflammatory reaction and oedema. Elective tracheostomy before interstitial PDT is implemented when managing advanced tumours in the oropharyngeal/laryngeal region. For example, a tracheostomy tube is inserted intra-operatively and kept for three to five days postoperatively. Intravenous steroids are also given for three days to reduce local inflammatory responses (Grant *et al.*, 1993; Hopper, 2000; Hopper *et al.*; 2004; Lou *et al.*, 2004; Jäger *et al.*, 2005; Jerjes *et al.*, 2009).

8. Conclusion

The concept of disease treatment has evolved from just two-dimensional static image that is captured by conventional radiological methods. Important considerations, such as the disease margin or the host/tumour interface, are a significant factor in eventual outcome. We now consider a tumour volume and slightly larger treatment volume to ensure a more logical and complete PDT treatment. This is aided by the use of computer modelling, a needle grid (to ensure parallel iso-doses of illumination) and timed illumination of fibres.

Ultrasound is necessary to help avoid vital structures during needle placement. In theatre we regularly have a specialist medical physicist to help conform to our iso-illumination treatment plan, reducing non-target treatment which results in side-effects from photo-activation. Our results show that the treatment is well tolerated and effective, especially for end-stage squamous cell carcinoma and advanced vascular anomalies. The great utility of this treatment modality is not only its repeatability (unlike radiotherapy), but the accuracy of treatment (to avoid unwanted bystander tissue damage, again unlike radiotherapy).

In summary, the growing body of evidence regarding the efficacy of PDT suggests that it will have a leading role in interventional oncology, especially with the development of image-guided interstitial PDT.

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MCQ – 43. The role of photodynamic therapy in the management of deep head-and-neck pathologies

1. Increased incidence of oral cancer in young persons is due to
    a. Improved surveillance leading to early detection
    b. Improved diagnostic methods
    c. Increased incidence of human papilloma virus infections in both genders
    d. Increase in consumption of tobacco and alcohol
    e. Surveillance by dentists

2. Photodynamic therapy should be considered
    a. As first modality of treatment
    b. As the forth modality of treatment
    c. As a palliative treatment
    d. As an adjunct to treatment with other conventional modalities
    e. For diffuse dysplasia

3. The *major* side effect is
    a. Gross tumour necrosis
    b. Considerable amount of pain in the treated area
    c. Prolonged photosensitivity
    d. Airway compromise
    e. Poor swallowing function

4. Recent improvements in the technique for accurate delivery are due to
    a. Better photosensitisers
    b. Better selection criteria
    c. Use of Ultrasound to help avoid vital structures during needle placement
    d. Use of special probes and shields which reduce non-target exposure
    e. Availability of specialist medical physicist to help conform iso-illumination treatment plan

Section VI: Laser Tonsil Surgery

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Chapter 44

Laser tonsil surgery

S. Kaluskar, J. Krespi, M. Remacle and A. Kacker

1. Introduction

Palatine tonsillectomy accounts for about a third of all otolaryngological surgical procedures. Therefore, it is hardly surprising that there has been a continuing quest to devise the optimum method of treatment. That any one particular method did not stand the test of time indicates either the ever-expanding inquisitive nature of the profession, the lack of finesse in the methodology so far, or a combination of both. The operation has been rated as requiring the lowest surgical skill and as a starting point for the surgical training of a budding otolaryngologist.

While a variety of methods has been tried, surprisingly, there is only one well-defined narrow objective: surgical removal of the diseased organ. Traditionally, this entailed the operation of tonsillectomy. Tonsillectomy must mean just that, a clean, visually complete removal of the tonsil. It should have minimum intraoperative bleeding. Postoperative bleeding, infection, and morbidity should be equitable with all methods. The learning curve should be easy, and the instrumentation cheap, re-usable and standardised so that a production line efficiency can be achieved with minimum costs.

So, have we been able to meet these very basic expectations? Obviously not, and hence every now and again, a new technology comes along and we think of high-tech tonsillectomy as a solution to the shortcomings of the old methods. This somewhat philanthropic approach has been introduced in the discussion that follows, because laser tonsillectomy has a high skill profile, and is not without complications. So, what do the antagonists like to hear and the protagonists like to push through? Is there a happy medium? Let us address some of these issues in the following pages; they may not stimulate the reader enough to go out and spend thousands of pounds instantly, but neither would they put him off the concept of laser tonsillectomy for life.

2. Evolution of tonsil surgery

Tonsillectomy was first described in AD 30 by Aulus Celsus, a Roman nobleman and author of a medical encyclopaedia. He wrote the first authenticated description of enucleation tonsillectomy in Book VII. He stated that, “The tonsil should be disengaged all round by the finger, and pulled out”. If this was not possible, Celsus advised “holding the tonsils with a hook and excising with a bistoury”. He advised that the wound should be washed with vinegar! He also described the attributes of a surgeon as, one of youthful or early middle age, with a strong and steady hand, as expert with the left hand as with the right, with vision sharp and clear, and spirit undaunted not to be moved by the cries of the patient to go too fast or cut less than necessary! Later on, Albucassis (AD 936-1013) was the first surgeon to use a form of tonsil guillotine.

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In 1700, Joseph Desault, a Parisian surgeon used a cystotome after hooking the tonsil to perform tonsillectomy (Weir, 1990). Other methods such as radium, X-rays and cryosurgery were recommended in the treatment of unhealthy tonsils, but were not accepted as they did not affect the core tissues of the tonsils. No significant developments occurred for quite sometime until Morell Mackenzie (1837-1892) popularised the technique of guillotine tonsillectomy, and made modifications on the original Physick (1828) tonsillotome. In 1910, Whillis (Weir, 1990) revolutionised guillotine tonsillectomy, introducing the tonsil into the aperture of the guillotine by pressing on the anterior pillar of the tonsil with a finger. By the end of the 19th century, tonsillectomy by guillotine had become a standard method. The technique fell into disrepute due to the higher incidence of tonsil remnants in the fossae and the higher incidence of reactionary haemorrhage, since no attempt was made to ligate the bleeding vessels. It was not until 1909 that George Waugh (1875-1940), who observed that many children with guillotine tonsillectomy suffered from a recurrence of sore throats due to large remnants in the fossae, described the dissection method of tonsillectomy and published his series of 900 cases in the *Lancet* (Waugh, 1909). With the introduction of endotracheal tube anaesthesia in 1920, dissection tonsillectomy became safer, with less operative and postoperative complications.

Cryoprobe application for unhealthy tonsils was introduced in late 1960s and early 1970s, but never gained popularity. In recent years, electrodissection tonsillectomy was described by Weinmart *et al.* (1990). In a retrospective study of 2431 tonsillectomies, they reported that the electrodissection technique was faster, and had minimal blood loss. However, the severity of pain and the degree of discomfort were related to the use of electrocautery. Pang (1995) used a bipolar electrodissection technique in 60 children and compared it with the dissection technique. He concluded that there was a statistically significant difference in intraoperative blood loss with bipolar dissection compared to the standard technique. However, there was no difference in the rate of postoperative haemorrhage between the two techniques. Goycoolea *et al.* (1982) reported tonsillectomy with a suction coagulator in 200 consecutive patients, and showed that the average bleeding per patient was minimal, but they encountered more postoperative oedema, a longer procedure, and healing problems.

Recently, tonsillotomy rather than conventional tonsillectomy has been performed with the CO_2 laser in children suffering from snoring and obstructive sleep apnoea (Linder *et al.*, 1999). These authors showed that tonsillotomy was much less painful, and that the children recovered more quickly compared to conventional tonsillectomy at the one-year follow-up.

3. Removal of the tonsil using a laser beam

A laser beam allows a bloodless initial incision along the anterior pillar in an inferior to superior direction. It can be accurately placed on the mucosal surface. Retraction of the tonsil allows good definition of the plane. The tonsil is separated gradually by bloodlessly vaporising the connective tissue in the plane. The process continues until the whole tonsil is detached and removed.

3.1. Concurrent haemostasis

The intense thermal energy in the laser beam separates the tonsil by vaporising loose areolar tissue between the tonsil and its fossa. During the process, there is also a collateral spread of the energy in the surrounding tissue. As most of the energy is concentrated at the point of vaporisation, the collateral energy level is low. The low level of collateral energy results in coagulation rather than vaporisation, and thus indirectly helps achieve concurrent haemostasis. Bleeding from capillaries and small size vessels is effectively controlled, and detachment of tonsil continues bloodlessly. In some cases, the laser may not control bleeding from large-sized vessels in the tonsillar bed. However, in most patients, the entire tonsil can be removed bloodlessly, the procedure taking, on average, no more than two minutes. The removal of the second tonsil in a similar way marks the end of the procedure, as there is no oozing and therefore no waiting time, as usually required in conventional tonsillectomy.

3.2. Which laser?

Having identified the various steps involved in tonsillectomy and how each method controls them, it may be possible to specify the parameters for an ideal laser, if indeed one is asked to design. The laser energy needs to be delivered easily along the tonsillar pillars from the superior pole to the lower pole at the base of the tongue. The energy should consist of two components: high enough energy for vaporisation, and some residual energy for haemostasis by coagulation. Vaporisation represents maximum, but not an entire expenditure of thermal energy. The residual energy spreads collaterally. The amount of residual energy is inversely proportional to the amount of vaporisation energy, and spreads exponentially from the point of impact. Thus, the extent of collateral spread is critical, since it governs the inflammatory response in the postoperative period and the thermal damage to the superior constrictor muscle fibres, with possible necrosis and pain.

Tonsillotomy as opposed to conventional tonsillectomy has been described for the relief of obstructive symptoms due to tonsillar hyperplasia with the CO_2 laser (Linder *et al.*, 1999). These authors showed that CO_2 laser tonsillotomy was uniformly effective in relieving the obstruction. The intraoperative haemostatis was good. The tonsillar remnants healed completely within two weeks, with no major complications occurring in their series of 33 children aged between one and 12 years of age. There was no gain in operating time compared with conventional tonsillectomy. In most cases, the operations were performed as a day procedure. No recurrence of obstructive symptoms was reported up to 20-23 months after surgery. They concluded that tonsillotomy using a CO_2 laser was a valid procedure for obstructive symptoms caused by enlarged tonsils.

3.2.1. The CO_2 laser

The CO_2 laser was one of the earliest to find a valuable role in ENT and its use became wide spread, particularly in laryngeal surgery. It was inevitable that tonsillectomy was soon advocated (Barron, 1987; Martinez and Akin, 1987; Nishimura *et al.*, 1988). The CO_2 laser, with its wave length of 10,600 nm, is an excellent cutter and can achieve reasonable removal of tissue in the incision line. However, its high water absorption parameter also means that collateral thermal spread is shallow, to the extent that it is not a good coagulator for haemostasis. The delivery system of articulated arms is somewhat bulky and cumbersome to work with in the depth of the oral cavity. Its surgical and aiming beam needs accurate alignment. The removal of tissue adjacent to the base of tongue is particularly difficult and sometimes causes copious bleeding due to the presence of the fair sized blood vessels in the vicinity of the tongue. A hollow waveguide delivery seems more user-friendly and the CO_2 laser has thus been used to vaporise the tissue for partial tonsillectomy (see below).

3.2.2. The Ho:YAG laser

The holmium:YAG laser has been used for tonsillectomy (Oswal *et al.*, 1992). Oswal *et al.* demonstrated that tonsillectomy was almost bloodless, but that there was some minor difficulty in mobilising the upper pole. Postoperative pain was no worse than routine tonsillectomy pain, and may have been less than would be expected. The tonsil bed healed within two weeks. Due to its high pulse energy and deep penetration, it was necessary to use it on the tonsil surface in order to minimise the depth of thermal damage in the tonsil bed.

3.2.3 The KTP/532 laser

Several workers (Raine *et al.*, 1995; Kaluskar, 1996; 1997; Auf *et al.*, 1997) have reported the use of the KTP/532 laser in recent years. One of the important evolutions in surgical lasers in recent years was the development of the potassium titanyl phosphate (KTP) laser, with a frequency of 532 nm. Unlike lasers in the infrared region, its emission in the visible range obviates any need for an additional aiming beam. Its absorption characteristics provide adequate thermal energy for vaporisation, and collateral penetration is sufficiently deep for effective intraoperative haemostasis.

The KTP laser beam can be guided down the flexible optical fibre and is therefore more versatile for access to narrow cavities. For tonsillectomy, it can be easily delivered right up to the lower pole. In common with all fibre-transmissible lasers, the beam parameters for cutting, vaporisation, and coagulation can be continuously adjusted by simply varying the target-to-tip distance. In the near contact position, it has maximum cutting energy. When increased haemostasis is required, it can be affected by simply drawing the tip away from the tissue. Irradiance and, therefore, vaporisation is reduced, collateral thermal spread increases, more tissue coagulates, resulting in greater haemostasis.

In addition to haemostasis by thermal coagulation, the KTP laser assists further haemostasis due to its high pigment absorption characteristics. The light absorption coefficient of the blood pigments, i.e., haemoglobin, peaks at 540 nm. The KTP laser emitting at 532 nm is highly absorbed by the haemoglobin, the blood vessels are coagulated, and therefore separation of the tonsil is bloodless in most cases. In theory, the incidence of reactionary bleeding should be less. Experience bears this out. In a series of 709 patients, reactionary haemorrhage occurred in 0.1% of patients (Kaluskar, 1997).

The flexible quartz fibre can be passed through a hand-held instrument, giving the surgeon the 'feel' of using a conventional instrument. The quartz endostat fibre is available in various sizes from 200-600 μm, thereby achieving different power densities and varying tissue interactions to obtain cutting, vaporisation, and coagulation effects on the tissues. The author routinely uses a 600-μm fibre for tonsillectomy. The quartz fibre tip remains cool, preventing accidental burns, to both the patient and the surgeon. Moreover, tissue adherence is less due to the cool tip, even in the contact mode, thus obviating the need for its frequent cleaning.

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MCQ – 44. Laser tonsil surgery

1. While removing tonsil with the laser
    - a. Stretching the tissue, as in conventional cold instrument tonsillectomy, facilitates its removal
    - b. Ensures that the laser beam strikes the fibrous capsule rather than the muscles in the bed
    - c. Minimises bleeding
    - d. Minimises postoperative pain
    - e. All of the above

2. The fibre can be used to
    - a. Feel the tissue
    - b. Dissect the tonsil
    - c. Use it as a cutter as well as coagulator
    - d. To seal large size blood vessels
    - e. All of the above

3. Using CO_2 laser
    - a. Tonsillotomy is easier than tonsillectomy
    - b. It is easy to remove the tonsillar tissue from the base of the tongue.
    - c. It is easy to seal blood vessels greater than 0.5 mm in diameter
    - d. It is easy to manipulate in the free beam mode
    - e. It is an ideal tool for tonsillectomy

4. The KTP laser is ideal because
    - a. It is fibre-transmissible
    - b. It is well absorbed by blood pigment
    - c. It does not require specialised eyewear
    - d. Its cutting effect depends on the distance from the target
    - e. The fibre has a single use specification and hence it is not cost effective

5. When using the KTP laser for tonsillectomy,
    - a. The beam should be directed away from the tonsillar bed
    - b. The dissection should take place on the fibrous tissue
    - c. If there is a large size bleeder in the bed, it should be controlled by repeated strikes of the laser beam
    - d. The fibre should be held in the hand on the same side as the tonsil being removed
    - e. The tip of the fibre should be kept clean of any debris or charred blood

6. Fibre deliverable laser has an advantage of
    - a. Being safe since it cannot result in accidental non-target strike (which is always a possibility when using the CO_2 laser in free beam mode)
    - b. Reduction in cutting power and increase in coagulating power simply by adjusting the distance between the tip of the fibre and the target
    - c. As the energy exits at the tip of the fibre, it diverges and loses its power.
    - d. Concurrent haemostasis: in order to increase its coagulating property, the fibre must be brought in close contact with the bleeder to provide sufficient thermal energy to stop the bleeding.
    - e. All of the above

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Chapter 45

Laser tonsillectomy

S. Kaluskar

1. Introduction

Before considering the application of laser technology for the removal of tonsils, it is useful to take stock of current practice and to identify the impact of the laser at each step of tonsillectomy. Tonsil surgery calls for complete removal of each tonsil. The procedure is accompanied by variable intraoperative blood loss. In the majority of cases, haemostasis is achieved by simple pressure with swabs and ligation of bleeding points. Some cases, particularly adults, require further measures such as diathermy, ligation, etc., before bleeding can be completely controlled. Intraoperative blood loss is said to be about 80-100 ml in routine tonsillectomy. The end-point of the procedure, dependent on achieving satisfactory haemostasis, is variable, and cannot be anticipated accurately, but the average time taken is about 25-30 minutes (De Brule, 1983). Postoperative reactionary haemorrhage can occur, with an incidence of 2-8% (Guida and Mattucci, 1990).

It is usual to keep the patient in hospital overnight, but practices vary according to socio-economic factors. In the postoperative period, there is considerable pain, usually requiring strong analgesics. Swallowing remains painful for a few days. The fossa is covered with slough, which usually clears within ten days. During this period, the incidence of secondary bleeding is in the range of 0.1-8.0% (Allen *et al.*, 1973; Kerr and Brodie, 1978).

It is indeed difficult to relate a postoperative haemorrhage in one study to that with others, as many different criteria are used to define postoperative bleeding, and in many publications, no firm definition is given. Incidence of postoperative haemorrhage is loosely defined, with confusion between primary and reactionary haemorrhage (Papagelou, 1972; Williams *et al.*, 1973; Malik *et al.*, 1982; Kristensen *et al.*, 1984; Kumar, 1984). The author suggests that secondary haemorrhage should be defined as any bleeding more than 24 hours after surgery, whereas reactionary bleeding is in the first 24 hours after surgery, and primary haemorrhage is during surgery.

The conventional method of dissecting the tonsils with scissors and a dissector results in trauma to the underlying superior constrictor muscle, which goes into spasm, leading to more delayed swallowing and stagnation of slough in the tonsil fossa. This may lead to secondary infection and bleeding, which could be either a minor episode or a serious complication needing a blood transfusion and return to the theatre for control of the bleeding.

2. KTP/532 laser tonsillectomy

The author has been using the KTP/532 laser (Laserscope, San Jose, CA) for tonsillectomy under general anaesthetic since 1991. Much initial work was undertaken to establish the optimum beam parameters, method of delivery of the energy, and surgical technique. What follows is a description of his own method and a review of various alternatives reported in the literature.

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2.1. Preoperative preparation

It is not always the case that the indicated power level on the console is also the actual power that is available at the tip of the fibre. Older machines do not perform well, and there may also be a loss during transmission due to damaged fibre or uneven cleaving. The efficiency of the quartz fibre is monitored so that at least 80% of the output energy is delivered at its tip. This is achieved by cutting it with a small diamond cutter and then cleaving its end (Fig. 1). It is then checked with a special device attached to the laser, which gives a reading of calibration. The patient's head is positioned for tonsillectomy, and the whole face is covered by a large piece of wet gauze with a hole for the mouth gag (Fig. 2). The mouth is opened with a Boyle Davis gag in the usual way to expose the tonsil fully. The specially designed tongue blade covers the entire tube from the lower incisors to the tongue base, and no part of the tube is exposed to an accidental strike of the laser beam (Fig. 3). A wet swab is placed on the posterior pharyngeal wall, and the edges are tucked under the posterior pillars to protect the tissues (Fig. 4). The surgeon and all theatre personnel must use the correct eyewear, specific to the KTP laser wavelength. A laser supervisor ensures that

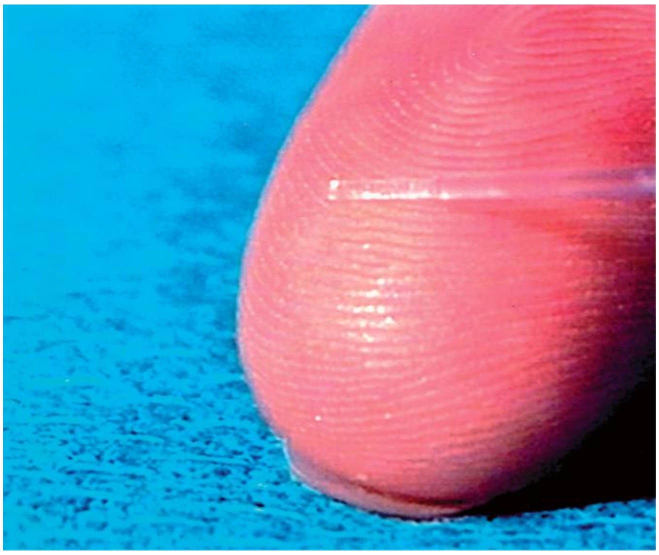

Fig. 1. A 600-mm quartz fibre cleaved prior to surgery.

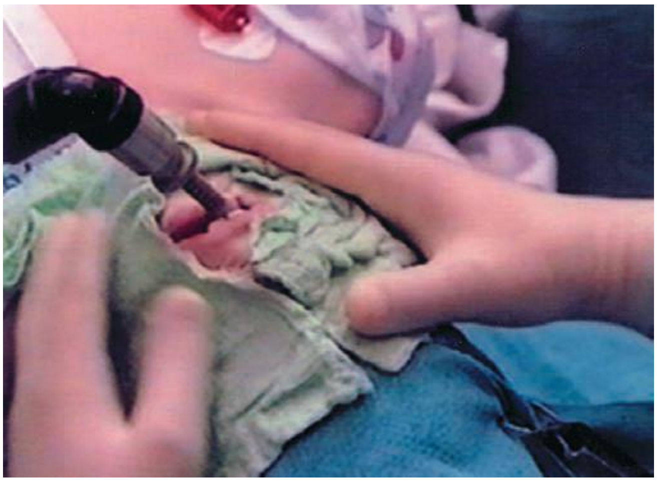

Fig. 2. Patient's face covered with moist gauze to prevent any accidental burn.

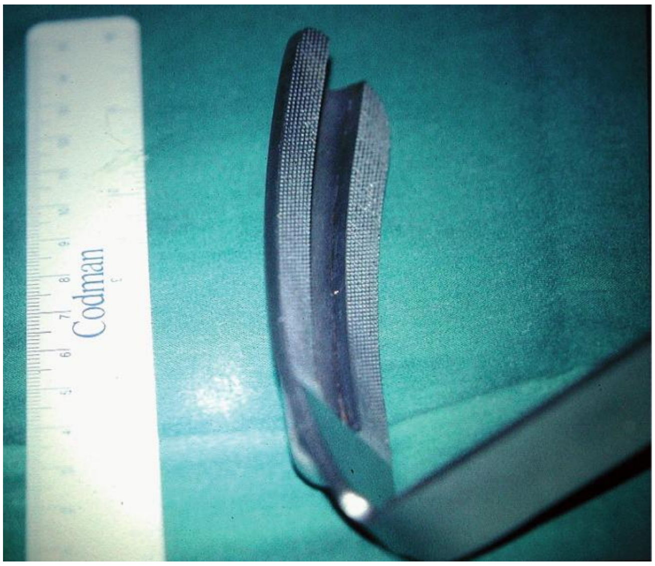

Fig. 3. The specially designed tongue blade covers the entire tube from the lower incisors to the tongue base and no part of the tube is exposed to the accidental laser strike.

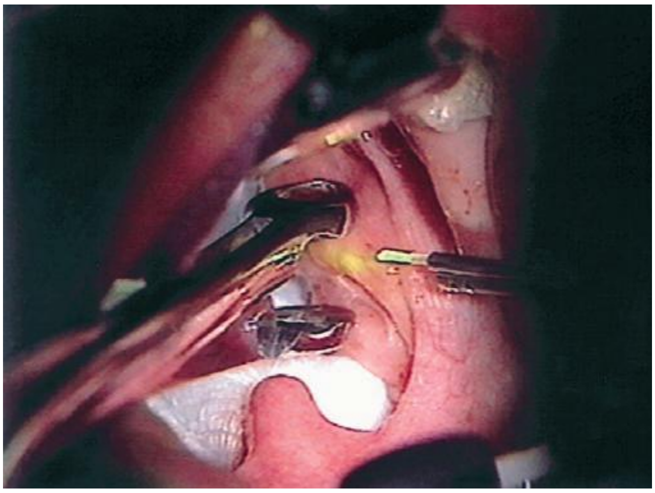

Fig. 4. Wet gauze is placed on the posterior pharyngeal wall to prevent non-target strike and the tonsil is retracted medially. The laser beam is in standby mode just before incision at the lower pole.

a safe working environment is established in the theatre.

2.2. Laser surgical principles for the removal of tonsils

In conventional tonsil removal, the loose areolar tissue between the tonsil and the bed is cut or avulsed with a dissector, and the tonsil pulled medially. Part of the loose tissue remains in the bed and part comes away with the tonsil. In laser tonsillectomy, the tonsil is detached by vaporising the tissue between it and the bed. However, only part of the energy is used up for vaporisation, the remainder is conducted to the deeper tissue beyond the plane of vaporisation. The conducted energy spreads in all directions and causes thermal damage with possible tissue necrosis. If the thermal damage spreads to the superior constrictor muscle, it will result in necrosis, muscular spasm, considerable post-operative pain, and increased morbidity. Histopathological studies (Mc-Naboe *et al*., 1998) with various laser parameters clearly indicate that the greater the energy fluence (total amount of laser energy: power density x time) imparted on the tissues, the greater the thermal damage to the deeper tissues. Therefore, the most important considerations are:

- to use the energy in short, sharp bursts to vaporise the areolar tissue so that the energy conducted is negligible; and
- to vaporise the tissue away from the tonsillar bed.

The finer details for achieving the above very specific requirements are described in some detail below.

The amount of energy required to vaporise a unit of tissue is directly proportional to its total volume. To reduce the volume or thickness of the tissue, the tonsil is fully stretched medially into the oral cavity before imparting the laser energy.

The site of the laser strikes must always be on the tonsil, and not in the tonsillar bed.

The direction of the beam must be away from the tonsillar bed. This can be achieved by the surgeon using the beam ipsilaterally and not crossing over to the contralateral side. Thus, the right tonsil is removed with the beam in the right hand and the left, with the beam in the left hand (Fig. 5).

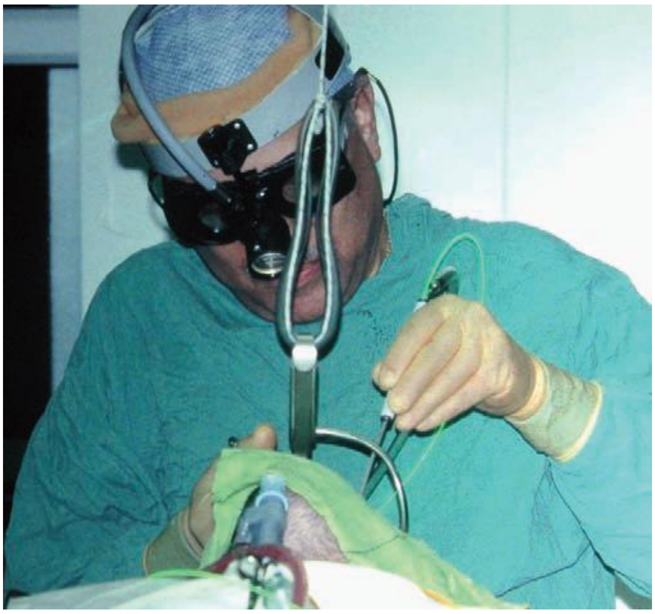

Fig. 5. The left tonsil to be removed with laser beam in left hand to facilitate easy separation of the tonsil.

2.3. Surgical technique

The anterior pillar is held and stretched medially. The output of the laser is set at 12 watts and the energy is delivered in the continuous and contact mode via a 600-µm quartz fibre (Fig. 6). Only in a small number of adults where scar tissue may be dense, an increased power of 14 or 16 watt is required.

The incision is started at the lower pole where the tonsil is relatively superficial and the cleavage plane well demarcated. When the tonsil is exposed in the incision line, it is grasped with

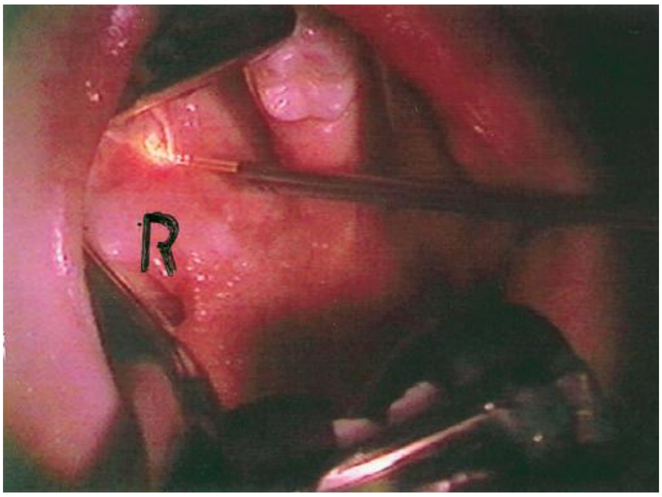

Fig. 6. Incision on the anterior pillar with the laser beam in *contact mode* in an inferior to superior direction following medial traction of the tonsil. R = right tonsil.

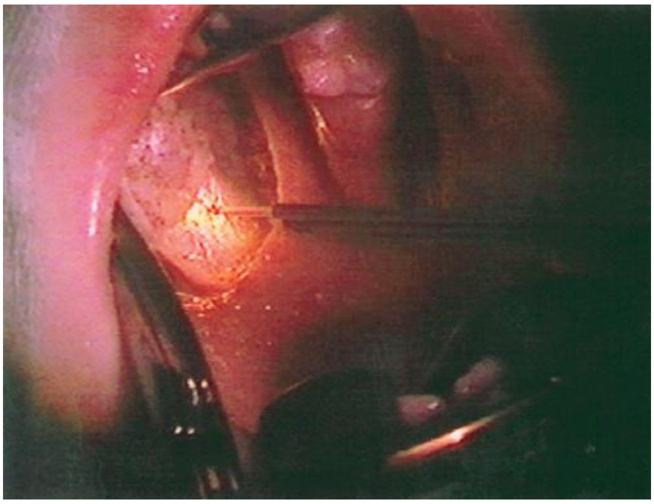

Fig. 7. Laser beam in *near contact* mode to vaporise loose areolar tissue between tonsil and its bed with medial traction maintained continuously.

Luc's forceps and stretched medially. The fibre tip is now withdrawn slightly so that it is in the near-contact position from the loose fibrous areolar tissue, which is vaporised by short excursions of the tip over it, much like an artist's paintbrush (Fig. 7). It is most important that the laser energy is delivered towards the tonsil tissue while separating the tonsil, rather than on the tonsil fossa. Any lateral thermal damage will be minimum by following this technique. The separation is continued towards the superior pole, taking care to avoid collateral spread to the base of the uvula. It then extends towards the posterior pillar and to the lower pole, keeping well away from the tongue base (Figs. 8A,B). It is important that the tonsil is removed swiftly and smoothly. Any laser energy directed towards the tonsil fossa, even for a few seconds, will result in lateral thermal damage and tissue necrosis.

The correct way to remove the tonsil is by vaporising the areolar tissue on the tonsil rather than in the bed. The right tonsil is removed with the laser beam in the surgeon's right hand and the left tonsil with the beam in his left hand. This technical detail is extremely important for ensuring that the beam direction remains on the tonsil and not on the tonsillar bed. The tonsil should be stretched fully so that the tissue to be removed is as thin as possible, requiring the least amount of energy being conducted into the fossa.

2.4. Haemostasis

During the entire separation of the tonsil from its fossa, the capillaries and small-sized vessels are sealed off. Any intact blood vessels seen under the mucosa are coagulated with short bursts of the laser beam in the non-contact mode. Control of active bleeding from large vessels with the laser requires considerable energy and even then, bleeding may not stop. These vessels should be ligated in the usual way. Under no circumstances should laser energy be used on the tonsil fossae in the contact mode to control active bleeding, as considerably more energy will be required. Thermal necrosis will be extensive in the superior constrictor muscle, with muscle spasm, increased pain, and postoperative morbidity.

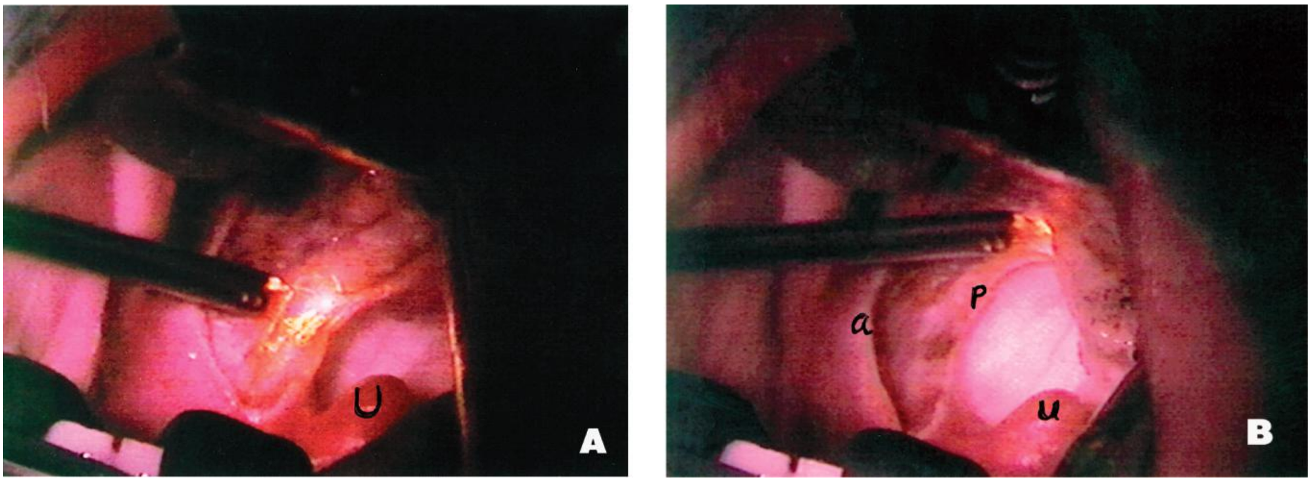

Fig. 8. A. Laser beam in *near contact* mode following separation of the tonsil from the upper pole and lasing towards lower pole. Note complete absence of bleeding and charring on the tonsil fossa. B. Laser beam in *near contact* mode at the lower pole.

The intraoperative bleeding with the laser is significantly less compared to the standard dissection tonsillectomy (Oas *et al.*, 1990; Kaluskar, 1997; Auf *et al.*, 1997). In the author's hands, the incidence of intraoperative bleeding is also significantly less with the KTP, following the technique described earlier. When fibrosis is present, the laser is used to 'cut' the fibrous bands by vaporising them. Any blood vessels in the fibrosis are not easily detected. They are also cut rather than coagulated. The intraoperative bleeding may occur in such cases, and may require conventional ligation.

2.5. Postoperative course (immediate – 24 hour)

Pain

It is well known that pain is an extremely difficult symptom to quantify, but it has been shown that, following laser tonsillectomy, the pain is minimal during the initial period of two to three days (Oas and Bartels 1990; Kaluskar, 1997; Auf *et al.*, 1997). However, in the author's experience almost half of the patients who had minimal pain, experienced increased pain at the end of one week, requiring more analgesia while the other half continued to have less pain. The reduced pain in the early postoperative period following laser tonsillectomy is believed to be due to the very precise nature of the separation of the tonsils, with minimal trauma to the fossa, and lack of exposure of the muscles in the tonsil bed. It is also probable that the laser energy destroys the sensory nerve endings during surgery, thus resulting in less pain.

Incidence of reactionary haemorrhage

Reactionary haemorrhage is defined as bleeding occurring within the first 24 hours after operation. It is believed to be due to slipping of the ligatures or opening of the small vessels, which remain in spasm during the operation. Carmody *et al.* (1982) described an incidence of 1.03% reactionary haemorrhage in their retrospective series of 3756 patients. Tami *et al.* (1987) showed a 2.7% incidence of reactionary haemorrhage in their series of 775 patients, and Roy *et al.* encountered 1.59% of patients who bled within the first 24 hours after operation. Raine *et al.* (1995) showed a 1.5% incidence of reactionary haemorrhage after KTP laser tonsillectomy in their 54 patients, and Kaluskar (1997) described the incidence of 0.1% in 706 patients with KTP laser tonsillectomy.

Incidence of secondary haemorrhage

Wasyl *et al.* (1996) reported a 2.8% incidence of secondary haemorrhage in 250 patients undergoing diathermy dissection, compared to 7.6% for dissection tonsillectomy. Carmody *et al.* (1982) reported a 3.7% incidence of secondary haemorrhage in adults. Szeremeta *et al.* (1996) reported a 7.6% incidence in 79 patients operated on by the dissection method and a 2.8% incidence in 250 patients operated on by the electrocautery method. Roy *et al.* (1976) showed a 3.71% incidence in 376 patients after the dissection method. Raine *et al.* reported 19% of secondary haemorrhages in their series of 54 patients operated on by KTP laser, whereas Kaluskar (1997) noted 1.1% in 706 patients operated on using the KTP laser, including one patient with Willi von Brand syndrome. Auf *et al.* (1997) reported 15% of secondary haemorrhages on the side on which the tonsils had been removed with the KTP laser in their series of 38 patients. This wide range of incidences of postoperative haemorrhage tends to show that the operation is probably surgeon- and technique-dependent. The Institute of Laryngology and Otology, London Report (1961–62) indicates a consistent 3% incidence of postoperative haemorrhage in a very large series of 18,184 operations. Williams (1967) found experience and surgical technique to be dominant factors in the reduction of incidence of postoperative haemorrhages.

Healing and re-epithelialisation

Healing of tonsil fossae appears to be similar following laser or conventional tonsillectomy, provided very little thermal damage is inflicted by the laser. However, Auf *et al.* (1997) stated that, when studying 38 patients operated on by the KTP laser, healing was slower on the laser side compared to the conventional side, but do not explain the method of determining the healing of the tonsil fossae.

2.6. Patient risk and benefit

Whenever there is a departure from the conventional methods, it is appropriate that the risk and benefit analysis be undertaken and the patient informed accordingly.

In the author's series of 1389 patients operated on with the KTP/532 laser using the technique described above, reactionary haemorrhage occurred in three patients (0.21%), all of whom bled within two hours postoperatively, all from one tonsil fossa, and who had to return to the theatre for ligation of the bleeding point. There were eight patients (0.57%) with secondary haemorrhage from this series of 1389 patients who had to return to the theatre. These included one patient who was later diagnosed postoperatively as Willi von Brand syndrome, a form of haemophilia. Of the eight patients, only one needed pillar suturing on both sides, while unilateral pillar suturing was performed in the remaining seven. All the secondary haemorrhages occurred in the early part of the series and after operations had been performed by three different surgeons, suggesting a learning curve on the part of the operator.

3. Discussion:

As already mentioned earlier, several factors influence the outcome of laser surgery for tonsils. Laser wavelength and the parameters play an important role to determine the penetration of energy within the tissue to a certain extent. However, the most important aspect of laser tonsil surgery is the technique in the application of the energy delivered via an optical fibre.

3.1. Operative technique

While range of parameters and the wavelength used can be standardized for consistency, the technique is very much dependent upon the training (or lack of it) of the individual operator. The latter has a direct bearing on the outcome measures and thus comparisons are flawed.

In a prospective double blinded randomised controlled trial of a cohort of 151 patients, Kothari *et al.* (2002) compared the efficacy of KTP/532 laser tonsillectomy verses conventional cold dissection and snare. The KTP/532 was used at 10W power setting in a continuous mode.

The outcomes measures were assessed using the following criteria:

- Operative times
- Intra-operative bleeding
- Postoperative pain and
- Postoperative swallowing

They reported that:

- There was no difference in the operative times; KTP/laser group averaged 12 minutes against 10 minutes for dissection group.
- Intra operative blood loss was greater for the dissection group (95 ml) when compared with the KTP laser group (20 ml).
- Pain was assessed with a visual |analogue score. It was higher for the laser group.
- Postoperative swallowing difficulty was greater in the laser group.
- Readmissions for secondary haemorrhage were 8% for the laser group as against 4 % in the dissection group.

In the author's opinion, a low power setting of 10W might have contributed to higher readmission rate. At low power settings, cutting effect is less efficient and the tissues tend to coagulate. Continuing use of laser at a low power setting results in conduction of laser energy within the tissue with even greater zone of coagulation and necrosis. The likelihood of secondary haemorrhage increases, with a greater readmission rate.

The author routinely uses the KTP/532 laser at a minimum power setting of 14W which effectively removes the tissue with vaporisation.

By inference, a low power setting may also have contributed to a longer operative time with the KTP/532 laser. The vaporisation of coagulated tissue is most inefficient, needing longer operative time.

Likewise, prolonged difficult in swallowing in laser group may also be the legacy of low power, resulting in more severe postoperative inflammation.

Auf *et al.* (1997) used 12W power setting in a continuous and contact mode. The tonsil was 'gently' retracted during its removal. The reported incidence of post operative bleeding was 15%.

The article does not indicate the diameter of the fibre used and also the calibration of the laser output. Laser output of less that 80% indicates a significant loss of effective power and results in a greater coagulation zone.

Efficient vaporisation of the loose areolar tissue in the tonsilar bed, superficial to the constrictors is a key to rapid removal of the tonsil, taking no more than two or three minutes. Rapid removal also results in minimum collateral damage with all its consequences.

The tonsil must be grasped well and pulled medially to stretch the loose areola tissue. In the author's experience, a power setting of 14W provides an optimum power to vaporise the tissue.

In children, where scar tissue is likely to be minimal in vast majority of patients, the removal can be achieved in less than two minutes.

The fibre must be used on the loose areolar tissue and should never be directed towards the tonsillar bed. Any bleed from minor vessels can be controlled with the laser, but laser should not be used for significant bleeding, say from a pulsating artery. Such bleeding should be controlled with conventional methods of ligation.

The essential technique for KTP/532 laser tonsillectomy is that the laser energy is always directed towards the tonsil and never to the tonsil bed so as to minimise trauma to the tonsil bed.

4. Intra- and postoperative management strategy

The author follows the following supportive regime for Laser tonsillectomy:

4.1. Dexamethazone

A single dose of dexamethazone (0.15 – 1mg/kg) is administrated I/V intraoperatively.

According to various authors (Krshina *et al.*, 2004, Steward *et al.*, 2001, Telin *et al.*, 1986), intraoperative steroids offer the following beneficial effects:

- Decreased pain by reducing inflammation & oedema
- Decreased nausea – Its empiric antiemetic effect is well known since steroids are also used for chemotherapy related vomiting. The exact mechanism of its antiemetic effect is not known.
- Mood elevation

4.2. Oral antibiotics

Oral antibiotics (Amoxycillin 250 mg.tid for 2 weeks) are prescribed for two weeks.

Post operative antibiotics have the following advantages:

- Decreased bacterial colonisation and thereby reducing inflammation
- decreased pain
- significantly less pyrexial incidence
- Improved oral intake
- Quicker healing

5. Pain

Takehisa *et al.* (1999) conducted a prospective study and reported advantages and disadvantages of KTP /532 laser tonsillectomy. Compared to conventional methods. KTP/532 laser offered a short operative time, reduced blood loss and less post operative pain in the early post operative period of up to 5 days. There was no post operative bleeding on the laser side.

However, the pain between the fifth and the eighth postoperative day was the same in both groups. This is in agreement with author's own experience. The pain is well controlled with simple analgesics and is not a major problem.

6. Collateral thermal damage

Umberto Romeo *et al.* (2010) studied the extent of collateral thermal damage during laser biopsy of oral tissue in a pig model and compared the findings with cold instrument biopsy.

Their finding was that the KTP/532 laser, while providing an efficient 'haemostatic surgical knife', also produced a minimum collateral thermal damage, thus allowing for a safe histological diagnosis.

7. New innovations for tonsillectomy

Recently, some newer techniques have been introduced for tonsillectomy. They are briefly described in the following paragraphs.

7.1. Bipolar vessel sealing device (BVSD)

Electro-coagulation process involves a sudden change in tissue characteristics, that occurs within a narrow temperature range, closely following the pattern of the applied current and is only modified by heat dissipation to the cooler parts, such as the forceps tips. A radiofrequency bipolar vessel sealing device (BVSD) does show that the operating time, post operative pain and bleeding is less than the conventional cold steel methods. This is also true for KTP/532 laser tonsillectomy having all the three advantages. KTP/532 laser by virtue of its wavelength is even a better coagulator than other newer techniques.

In a prospective, randomized, clinical study Hegazy *et al.* (2008) compared the advantages and disadvantages of KTP laser with those of bipolar radiofrequency techniques for chronic tonsillitis in paediatric population. Patients were prospectively randomized into 2 equal groups: KTP laser tonsillectomy (n = 40) and bipolar radiofrequency tonsillectomy (n = 40). The outcome measures included; operative time, intra-operative blood loss, post-operative pain, and rate of post-operative complications. Follow-up visits were scheduled during the first, second and fourth post-operative weeks. Patients were asked to record their pain and discomfort on a standardized visual analogue scale (VAS).

Operative time: operative time ranged 6 to 14 minutes in the radiofrequency group and 9 to 15 minutes in the KTP laser group. However, shorter operative time was not statistically significant.

Intra-operative blood loss ranged from 25 to 35 ml in the radiofrequency group and 21 to 30ml in the KTP laser group. The mean difference of 9ml was statistically significant.

VAS: During the first post-operative week pain and discomfort range of scores from 7.5 to 9.5 for the radiofrequency group and 6 to 9 in the KTP laser group. The difference was not statistically significant.

During the second post-operative week pain and discomfort range of scores had increased for the KTP laser group (range 7.5 to 9.5) compared with a decrease in the radiofrequency group (range 5 to 7), This difference was also not statistically significant;

In the fourth post-operative week, both groups showed an equal improvement in pain score.

Post-operative complications: The authors noted there was no statistically significant difference between the two groups. However, the article did not provide complication rate data for the treatment groups or the overall rate of complications.

The authors concluded both KTP and the bipolar radiofrequency techniques were safe and easy to use for tonsillectomy.

7.2. The ultrasonically activated scalpel

The ultrasonically activated scalpel (harmonic scalpel – Ethicon Endo Surgery INC – Johnson & Johnson Medical SPA, Somerville, NJ) also shows that the post operative bleeding is significantly less than the conventional methods. This is due thermal coagulation. Furthermore, the temperature obtained and the lateral energy spread are lower than that with monopolar cautery. There is thus less collateral damage. KTP 532 has similar properties if used with correct technique.

8. Conclusions

In common with other sites, the tissue effect in laser tonsillectomy is dependant on the wavelength used, the beam parameters, and tissue type. However, surgical skill seems to be the most important factor to influence surgical outcome. Fibre-transmissible lasers are superior as they allow infinite variations in irradiance. The depth of the thermal damage zone in the fossa is minimised by ensuring that energy is imparted on the tonsil rather than on the fossa. Any temptation to use the laser for haemostasis of large-sized vessels should be avoided, as this will result in deep thermal damage extending to the superior constrictors. During the learning curve, it is important that laser tonsillectomy preferably be undertaken in children whose tonsils are less fibrous. A period of self-audit is very useful for improving and refining the technique. The procedure can then be extended to adult tonsillectomy, in which the plane is usually ill defined.

A higher incidence of complications and ineffectiveness of the KTP laser for tonsillectomy have been reported by other authors (Raine *et al.*, 1995; Auf *et al.*, 1997). However, this has not been borne out by Kaluskar (1997), who found that KTP/532 laser tonsillectomy is a quick, repeatable, and safe procedure, with a surgical outcome comparable to conventional methods. Surgical and anaesthetic time is short, with acceptable or even better postoperative morbidity. There is very little intraoperative bleeding when the correct technique is used and when there is clear appreciation of KTP/532 laser-tissue interactions. The author routinely performs day case tonsillectomy in a selected group of patients, as per the criteria laid down by the Royal College of Surgeons in the UK.

Increased secondary haemorrhage and delayed pain has largely been attributed to thermal injury to the tonsil fossae (Oas and Bartels, 1990; Auf *et al.*, 1997). Therefore, it is extremely important that lasing should always be directed towards the tonsil, and not towards the fossae.

It cannot be overemphasised that the laser is not just another refined pair of scissors, a dissector, or scalpel. Although its action may be likened to diathermy, its effects are more precise, and, with the correct technique, more predictable.

There is always a room for refinements in tools. However, a randomised prospective study, comprising of time honoured gold standard method of cold steel dissection and the newer surgical tools is necessary. Other factor such as the capital outlay, the cost of consumables, standardisation of methodology and the skill level will always crop up in the debate alongside the usual surgical outcome measures, for deviating from the long established gold standard of cold steel surgery. The Jury has a long way to come home to roost.

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MCQ – 45. Laser tonsillectomy

1. In order to achieve consistent results of laser tonsillectomy
    a. The power setting should vary according to the size of the hypertrophied tonsil
    b. The more commonly used laser, namely, the CO_2 laser, should be used
    c. It is necessary to develop a protocol for the laser setting and the surgical technique
    d. A period of learning curve is necessary
    e. The ‘feel’ should be familiarised by using it first in adult tonsillectomy

2. The KTP is a used with a fibre for its delivery to the tonsil
    a. And therefore there is no concern of the ignition of the anaesthetic tube, since the energy exits very close to the target tissue
    b. Even then there is always a danger of reflection from the instruments resulting in ignition and therefore protection of the anaesthetic tube is mandatory
    c. However, hot exploding debris can still cause ignition of the anaesthetic tube
    d. However, there is a possibility that the beam may escape prematurely if the cladding and the fibre is damaged anywhere along its course
    e. Its single use marketing specification ensures that there is no damage to the fibre

3. Single use specification
    a. Ensures that the energy delivered at the tip of the fibre is consistent since the fibre wear and tear is minimum
    b. It protects the patients from cross infection
    c. If reused for the same patient for subsequent repeat operation the tip can be freshened by cleaving with a tool provided by the manufacturers
    d. Is cost effective

4. Wavelength specific eyewear
    a. Is not necessary since the energy exits at the tip of the fibre which is deep in the oral cavity
    b. Is necessary since the visible KTP laser can go through all the structures of the eye and damage the retinal blood supply
    c. Ordinary prescription glasses will protect the eye from laser injury
    d. An aversion reflex is sufficient to protect the eye from laser injury

5. Collateral thermal tissue damage
    a. Means damage in the surrounding non-target tissue
    b. Can be minimised by meticulous surgical technique
    c. In the surgical bed, may result in slough formation and postoperative bleeding
    d. On the tonsil tissue being removed, is of no consequence
    e. All of the above

6. Collateral thermal tissue damage is more likely
    a. If the fibre is held in the contralateral hand, since the tip will be ‘naturally’ directed to the tonsillar bed
    b. If the tonsillar tissue is much fibrosed, since fibrosis does not contain much water and therefore the laser energy cannot efficiently ablates the tissue
    c. If the tissue is charred rather than vaporised
    d. If the bleeding on the bed is stopped with repeated laser strikes
    e. All of the above

7. Short bursts of exposure of the laser energy
    a. Should be avoided since it prolongs the operating time
    b. It results in increased collateral damage
    c. Results in less collateral damage since the intervening 'off' time allows tissues to cool down before the next strike, thus limiting the overall rise in temperature which inevitably will spread to the deeper tissue
    d. Unnecessarily results in prolonged anaesthetic time and adds to the in-patient stay and overall morbidity

8. With the KTP laser, concurrent haemostasis is achieved because
    a. It is well absorbed by haemoglobin in the *intact* blood vessel, which immediately coagulates
    b. It is well absorbed by free blood oozing from the severed blood and causes haemostasis
    c. It is well absorbed by free blood oozing from the severed blood vessel and therefore fails to cause haemostasis
    d. It has no effect is causing haemostasis if the blood vessel is already breached and the blood is flowing out freely
    e. Repeated strikes on a bleeding vessel, far from being effective in causing haemostasis, will result in charring and much collateral damage

9. Pain following KTP tonsillectomy
    a. Is less sever initially
    b. Is much worse initially
    c. Is the same as compared to cold instrument tonsillectomy
    d. It is less initially but same as cold instrument tonsillectomy after a few postoperative days

10. Postoperative secondary bleeding following KTP laser tonsillectomy
    a. The finding is not consistent between the various workers
    b. The incidence improves with the learning curve
    c. The incidence is related to the laser technique
    d. All of the above

11. For any surgeon who wishes to embark on KTP (or diode) laser tonsillectomy
    a. It is necessary to learn the laser surgical technique
    b. Initially, the laser should be used for paediatric tonsillectomy where the tissue plane is relatively easy to obtain due to lack of fibrosis
    c. It is necessary to keep a record of laser parameters used and modify them following self-audit, if necessary
    d. It is necessary to ensure that the energy available at the tip of the fibre is consistent with the reading displayed on the console, by regular calibration
    e. It is necessary to clean the tip of the fibre frequently and cleave, if the laser spot is distorted
    f. All of the above

Chapter 46

Laser-assisted serial tonsillectomy

J. Krespi and A. Kacker

1. Introduction

Chronic tonsillitis is the commonest indication for tonsillectomy in adults. The crypts in palatine tonsils can become obstructed with impacted debris, or simply act as a harbouring site for bacteria. Palatine tonsillectomy has long been the accepted surgical modality for the treatment of chronic tonsillitis. Although newer instrumentation and safer anaesthesia techniques have reduced the morbidity associated with tonsillectomy, the need for general anaesthesia, the postoperative pain, and the risk of haemorrhage remain significant drawbacks to this procedure. In the adult population, some of these drawbacks can be avoided through the use of the CO_2 laser for serial ablation of the palatine tonsils in an office setting. The indications, technique, and efficacy of this novel procedure will be discussed in this part.

2. Clinical indications

Recurrent infection of the palatine tonsils remains a common affliction in the general population, particularly in paediatric patients. Chronic tonsillitis is the most common indication for tonsillectomy, a procedure that numbered 74,000 cases in 1990 (National Centre for Health Statistics, 1991) in the USA. Tonsillar crypts have been shown to represent an important site for antigen presentation and processing in the tonsillar lymphoid tissue (Perry and Slipka 1993; Reibel and Sorensen, 1991). Persistent bacterial colonisation or inflammation secondary to trapped debris within the tonsillar crypts may be important causes of recurrent tonsillitis, halitosis, and dysgeusia (Fig. 1). The morbidity associated with palatine tonsillectomy has been studied extensively (Handler *et al.*, 1986; Capper and Randal, 1984; Tami *et al.*, 1987; Colclasure and Graham, 1990; Kristensen and Tvetares, 1984; Crysdale and Russell, 1986; Tan *et al.*, 1993; Tay, 1995; Nicklaus *et al.*, 1995). The commonest risks include bleeding, which can be classified as either intra-, early post-, or late postoperative. Intraoperative bleeding is technique-dependent and can be negligible to massive. Early and late postoperative bleeding have a similar incidence of approximately 3%. Postoperative pain represents the most common morbidity due to this operation. Pain tends to subside after about 14 days, once the tonsillar fossa has healed with mucosal lining.

In the adult population, the CO_2 laser can be used in the office setting to ablate the palatine tonsils when treating chronic tonsillitis. This procedure can also be performed in conjunction with laser-assisted uvulopalatoplasty for treating snoring or mild obstructive sleep apnoea.

3. Technique

Whether serial-tonsillectomy as described here or tonsil ablation as described by Remacle (2003), the procedure is carried out in the sitting position without the use of a mouth gag. The patient and the

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office staff are equipped with safety goggles, and laser safety standards are carefully followed. The oropharynx is anaesthetised by a topical anaesthetic spray such as benzocaine 20%. After several minutes, a 1-ml mixture of 2% xylocaine with 1:100,000 epinephrine and 0.5 ml 0.5% bupivicaine is injected into the superior junction of the anterior and posterior pillars, and the midportion of the anterior pillar. According to Remacle (2003), for small tonsils, tonsillar remnants, or tonsillar cysts, local anaesthesia is achieved with 10% lidocaine spray alone. For large tonsils, peritonsillar infiltration is undertaken with 2–5 ml of 1% lidocaine mixed with 0.5% adrenaline. The patient is instructed to inhale deeply before the passage and activation of the laser, and to exhale slowly over ten to 15 seconds while laser energy is being applied. Inspiratory replenishment is cued by the surgeon only on deactivation and withdrawal of the laser. This coordination is important for several reasons: it allows relative relaxation and stabilisation of the soft palate and tongue, helps to keep these structures away from the path of the laser and minimises laser plume inhalation.

The author uses the Oral Pharyngeal Delivery Handpiece and the SurgiTouch™ scanning system (Lumenis, Santa Clara, Calif.) which ensures a uniform sweep (Remacle, 2003). The SwiftLase scanner is a battery powered accessory for the conventional CO_2 laser, and distributes focused laser energy over a 4mm treatment area in milliseconds, through the use of rotating mirrors. The laser energy is set at 15-18 watts in the continuous mode. While the patient is exhaling, the pharyngeal handpiece (Fig. 2) is used to serially ablate the tonsil in a painting pattern. Four to six passes (10-15 seconds per pass) are used to complete the treatment of each tonsil (Fig. 3). The tonsils are ablated to the level of the pillars only. Avoiding injury to the pillars significantly reduces the postoperative pain. Repeat treatments can be carried out at four-week intervals.

Remacle *et al.* (2003), aim at retaining a tissue layer of 10–20% of the tonsil volume rather than totally vaporising the lymphoid tissue (Fig 4a, b, c).

Intravenous steroids are not routinely used. Postoperatively, diluted peroxide rinses (three times a day) and throat lozenges are advised for five days in order to promote the removal of debris and laser coagulum. Postoperative antibiotics are used for a period of one week, and postoperative analgesics are prescribed on an individual basis. On discharge, most patients can tolerate a soft diet, and quickly advance

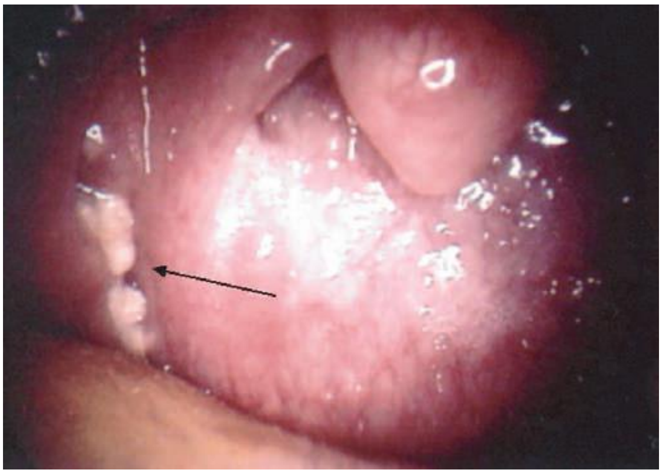

Fig. 1. Formation of tonsillolith results from debris trapped in the crypts and results in the reservoir for recurrent secondary infection.

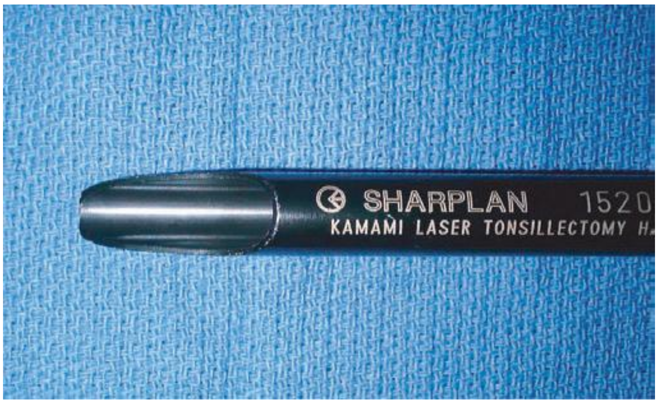

Fig. 2. Kamami Handpiece for vaporisation of tonsil tissue with CO_2 laser.

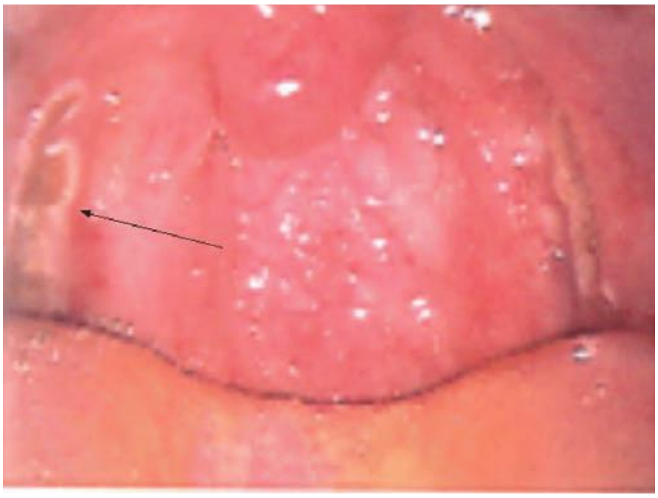

Fig. 3. CO_2 laser ablation of the palatine tonsils. Tongue blade is positioned laterally to expose the tonsil.

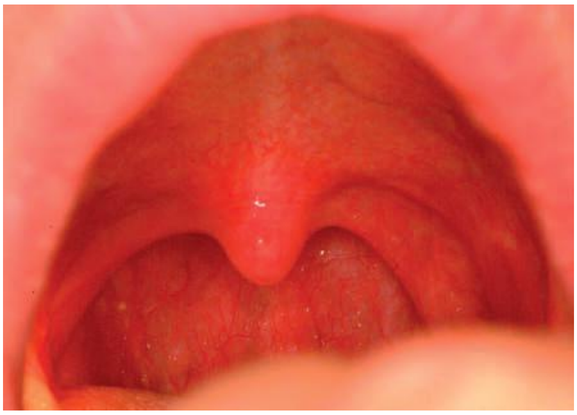

Fig. 4a. Palatine chronic and hypertrophic tonsillitis. Adult patient.

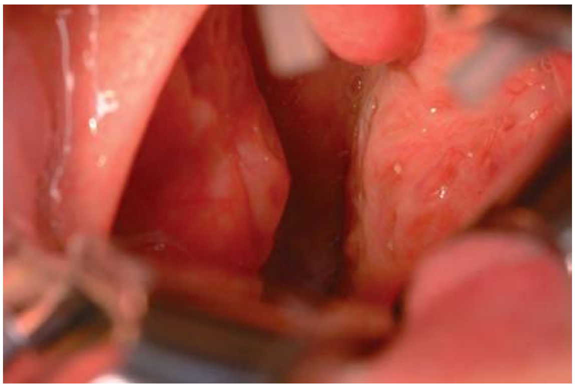

Fig. 4b. Subtotal ablation with the acublade.

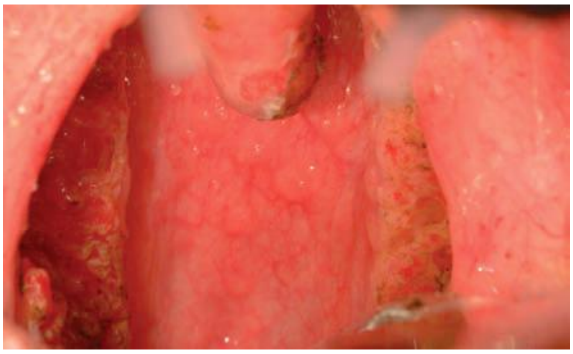

Fig. 4c. View after healing.

to a regular diet at home. The patient often returns to work immediately.

4. Patient risk and benefit

In a study of 120 adult patients, Krespi and Ling (1994b) reviewed the results of laser-assisted serial tonsillectomy. Ninety-two percent of the patients were treated in the office under local anaesthesia, and 8% were treated in the operating room under general anaesthesia; 96% of the patients experienced complete relief from recurrent tonsillar inflammation during a two- to 48-month follow-up. Twenty patients (17%) required more than one treatment. Only five patients (4%) reported insufficient improvement, and underwent completion tonsillectomy using traditional methods.

There were no immediate postoperative complications in this study. The postoperative level of discomfort was described as minimal, and well tolerated with oral analgesics (acetaminophen with codeine and viscous xylocaine). The degree of inconvenience was likened to a typical visit to the dentist. There were no reports or complaints of bleeding, rhinolalia, velopalatine insufficiency, or dysphagia beyond the initial postoperative period.

Similarly, Remacle *et al.* (2003) studied 66 patients undergoing tonsil ablation under general (17 pts. – 26%) or local (49 pts. – 74%) anaesthesia. By reviewing postoperative pain through clinical examination and patient questionnaire, they came up with a satisfaction score of 10 (range: 1–10) for the general anaesthesia (GA) group and of 8 (range: 1–10) for the local anaesthesia (LA) group. Moreover, when asked if they would recommend the operation and would undergo the same surgery again, 40 of the 49 patients (82%) of the LA group and 16 of the 17 (94%) patients of the GA group answered positively, thus proving a very high satisfaction rate.

5. Anatomical basis

Recurrent cryptogenic tonsillitis and recurrent tonsillolith formation are frequently treated with conventional tonsillectomy. Our understanding of tonsil anatomy and its histopathology on the one hand, and innovations of the laser technology on the other, provide the link between the theoretical framework and practical application of laser-assisted serial tonsillectomy. While traditional tonsillectomy relies on extirpation, laser serial tonsillectomy offers an efficacious alternative treatment for these common tonsil problems.

Tonsillar crypts have been identified as an important site of primary immune antigen processing and response, which can lead to palatine tonsil inflammation. In addition, tonsillitis may also result from secondary infection related to the unique architecture of the tonsils. This inflammation could be the principal underlying cause of sore throats, halitosis, and dysgeusia.

The three-dimensional structure of the tonsillar crypts has been elucidated, noting the simple non-branched crypts at the periphery and complicated branched units centrally (Abbey and Kawabata, 1988). Just beneath the crypt epithelium are capillary vessels and lymphoid tissue (Higashikawa *et al.*, 1990). Changes in these capillary vessels correspond to the initiation of tonsillar inflammation (Fujihara, 1991). While this crypt architecture increases the surface area available for the microscopic capturing and processing of antigenic material (Brandtzaeg, 1984), debris can be trapped and become the reservoir for recurrent secondary infection or the focus for tonsillolith formation (Cooper *et al.*, 1983). The ablation of tonsillar crypts, through the use of the CO_2 laser, eliminates this reservoir or focus.

Although laser treatment, as described here, is a surface ablating procedure, tissue beyond the superficial openings of the tonsillar crypts is affected by the thermal spread of laser energy. After healing, some crypts may undergo fibrosis and become obliterated. These closed crypts no longer collect antigenic or pathological debris that can initiate inflammation. Other crypts maintain an epithelial lining and become marsupialised, with persistent opening analogous to a sinus. Crypts open in this manner may trap less debris or permit discharge, despite surrounding inflammatory swelling. Moreover, laser ablation of subepithelial capillaries limits their role in the development of potential inflammation. The diminished ability of antigen entrapment, and the reduced subepithelial vascularity, may account for the clinical improvement noted in the patients treated.

Patients or practitioners who have reservations about tonsillectomy should consider laser-assisted serial tonsillectomy as a tissue-conserving procedure. Tissue preservation is important for individuals in whom voice alteration is undesirable, such as professional speakers or singers. Laser assisted serial tonsillectomy avoids significant changes of the tonsil bulk or scarring of the faucial arches, and therefore maintains the position of the soft palate, leaving the voice intact.

6. Conclusion

Chronic inflammation of the tonsils has been treated by many therapies, from the application of iodine and massage in the pre-antibiotic era to today's common tonsillectomy. Although traditional tonsillectomy has proved to be a very effective surgical treatment for chronic tonsillitis, the associated morbidity and cost have inspired other therapeutic modalities. In appropriately selected patients, laser serial tonsillectomy may be able to provide the efficacy of traditional tonsillectomy with reduced cost and morbidity. The two studies involving investigation of the long-term effects of intracapsular partial tonsillotomy through questionnaires, whether for sleeping disorders (Hultcrantz, 2005) or for recurrent chronic tonsillitis (Andrews, 2004), proved the long-term reliability of this method. Large, controlled, prospective studies will be necessary to compare these two surgical modalities.

According to the authors' experience, laser assisted serial tonsillectomy offers some clear advantages, particularly when performed with the SwiftLase apparatus. The procedure can be performed safely in an ambulatory surgery or office setting under local anaesthesia. The patient avoids the cost and risk of general anaesthesia. Limited tissue destruction significantly reduces operative and postoperative complications, discomfort, and recovery time (Krespi, 1993; Krespi and Ling, 1994; Remacle, 2003). In conclusion, laser-assisted serial tonsillectomy is a safe and cost effective method of treating tonsil pathology without unnecessary sacrifice of the organ, or undue risk and expense to the patient.

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MCQ – 46. Laser-assisted serial tonsillectomy

1. The most common issue with conventional tonsillectomy is
    a. The cost
    b. Loss of work
    c. Postoperative bleeding
    d. Postoperative morbidity (pain)
    e. Need for a general anaesthetic

2. For office based serial tonsillectomy, it is necessary to have
    a. A cooperative patient
    b. A dedicated hand-piece with scanner attachment for smooth delivery of the laser energy
    c. A mouth gag
    d. A patient in a recumbent position
    e. Local anaesthetic with sedation

3. Each tonsil is ablated
    a. Until the fibrous capsule is reached
    b. To the level of the pillars
    c. According to some surgeons, until 10% - 20% of the tonsil tissue is left behind
    d. Until all the crypts are ablated
    e. All of the above

4. Chronic tonsillitis is due to
    a. Hypertrophy of the tonsils in response to several bouts of acute tonsillitis
    b. Buried tonsils with minute crypts which fail to drain adequately
    c. Reaction of tonsil tissue with antigenic substances which results in repeated bouts of acute inflammatory response
    d. Retention of debris in crypts
    e. All of the above

5. Following serial tonsillectomy
    a. Steroids are prescribed to reduce oedema
    b. Antibiotics are prescribed routinely
    c. Incidence of postoperative bleeding is comparable to the conventional tonsillectomy
    d. Postoperative pain is comparable to the conventional tonsillectomy
    e. Resolution of symptoms does not take place in every patient and conventional tonsillectomy is advised

Chapter 47

Laser management of the lingual tonsils

J. Krespi, A. Hantzakos and A. Kacker

1. Introduction

The most common abnormality of the lingual tonsils is papillary hyperplasia. Although Waldeyer's ring tends to atrophy with age, the lingual tonsils can enlarge with allergy or chronic infection. Lingual tonsil hyperplasia is also encountered in patients with obstructive sleep apnoea (OSA). Symptoms of lingual tonsil disease range from mild throat irritation to the feeling of choking and respiratory obstruction. The mainstay of therapy remains nonsurgical.

When conservative therapy fails, patients can often benefit from surgical intervention. Lingual tonsillectomy has undergone tremendous change with the advent of new instrumentation and technology. Patient selection is critical in facilitating laser use.

2. Clinical setting

The lingual tonsil consists of lymphoid tissue incorporated within Waldeyer's ring, and sits at the base of the tongue between the circumvallate papilla and vallecula. It comprises two large laterally placed clumps of lymphoid tissue divided by the median glosso-epiglottic fold. The size and deposition of this tissue are quite variable. Unlike the other lymphoid organs that compose Waldeyer's ring, the lingual tonsil does not involute with age, but can actually increase in size in response to environmental allergens or irritants. Speculation exists that this hyperplasia is a compensatory mechanism following palatine tonsillectomy and adenoidectomy (Goeringer and Vidic, 1987; Wood and Whittet, 1989).

Diseases of the lingual tonsils and their treatment have long been ignored in both clinical practice and the medical literature. Physicians tend to overlook this anatomical area in their physical examination, differential diagnosis, therapeutic planning, and intervention. The rich vascular supply from the dorsal lingual artery that arises from the external carotid artery often makes transoral surgical excision of the lingual tonsils hazardous, particularly without proper equipment and experience. The lymphatics drain into the suprahyoid, submaxillary, and deep cervical nodes. Sensory innervation is by way of the IXth and the superior laryngeal branch of the Xth cranial nerves. (Elfman, 1949; Elise, 1959).

Lingual tonsil hyperplasia is by far the most common pathological state. Most often, the hyperplasia is a response to allergens and irritants such as smoke and dust, or a result of chronic gastroesophageal reflux. Hormonal and immune mechanisms may also play a role in this enlargement. The incidence of lingual tonsil hyperplasia is greater in females than in males.

Clinically, lingual tonsil hyperplasia may manifest in a myriad of symptoms. These include constant throat irritation and globus, to the more serious complaints of choking and dysphagia. In obese individuals, lingual tonsil hypertrophy can contribute greatly to OSA (Jesberg, 1956; Olsen *et al.*, 1981;

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Wilson *et al*., 1989). Conservative treatment includes avoiding the irritants or eliminating the inciting aetiologies, and is often successful in obviating the need for surgical intervention.

Lingual tonsil hyperplasia can also result from infectious aetiologies. Patients with acute lingual tonsillitis or chronic irritative tonsillitis usually respond to medical therapy. Antibiotics are the mainstay of therapy. Surgery is rarely indicated. However, in patients with chronic lingual tonsillitis refractory to antibiotics or patients with excessively enlarged lingual tonsils, surgical intervention can often bring relief and provide satisfactory resolution (Joseph *et al*., 1984; Newman and Johnson, 1979).

The traditional surgical armamentarium for lingual tonsillectomy includes scalpel, scissors, the special 'lingual tonsillectomy snare', electrocautery, and the cryoprobe (Cohen, 1917; Sluder, 1917; Hoover, 1934). Excision by sharp dissection is uncommon, and remains an unpopular choice due to uncontrolled haemorrhage. Other surgical complications, such as postoperative oedema with resultant airway compromise, have dissuaded surgeons from performing lingual tonsillectomy. Cryosurgery has its advocates, but poor control of tissue damage with the cryoprobe has led to its demise as a surgical tool (Principato, 1987; Von Leden and Rand, 1967).

The CO_2 laser has proved to be superior to other surgical techniques in treating lingual tonsils. It is the ideal method for base of tongue surgery due to its precision and excellent haemostatic capability (Mihashi *et al*., 1976; Strong *et al*., 1973; Wouters *et al*., 1989). Furthermore, it seals lymphatic vessels and nerve endings, thereby decreasing postoperative oedema and discomfort. The avoidance of trauma to adjacent normal tissue is achieved, thus allowing more rapid healing.

3. Indications and patient selection

The indications and patient selection for laser lingual tonsillectomy are important components of patient care. A diagnosis of lingual tonsil hyperplasia needs to be made following full assessment. The medical evaluation includes a careful history and physical examination with fibreoptic visualisation of the upper aerodigestive tract and an allergy assessment if indicated. Patients with symptoms and findings consistent with lingual tonsil hyperplasia are placed on a two-week course of antibiotic therapy. The majority of patients should also be treated with an anti-reflux regimen. This consists of a combination of H2 blockers and antacids or proton pump inhibitors. Medical therapy must be rigorously reinforced and closely monitored through regular office visits. A flexible laryngoscope is used to follow and document the clinical course after therapy has been instituted. If, after four weeks of aggressive medical therapy, the patient's symptoms persist, surgical intervention should be contemplated.

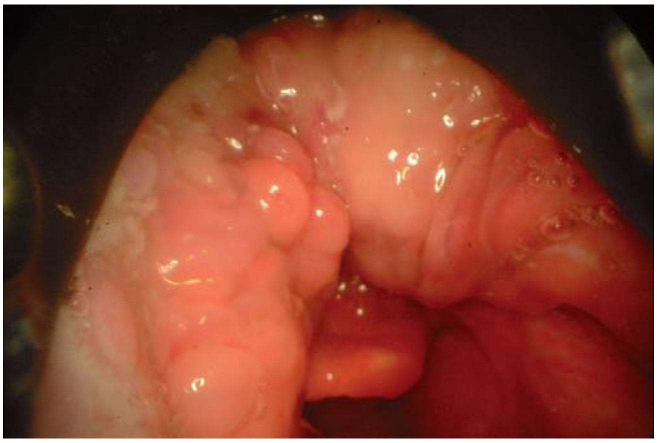

Fig. 1a. Shows massive hypertrophy of lingual tonsil.

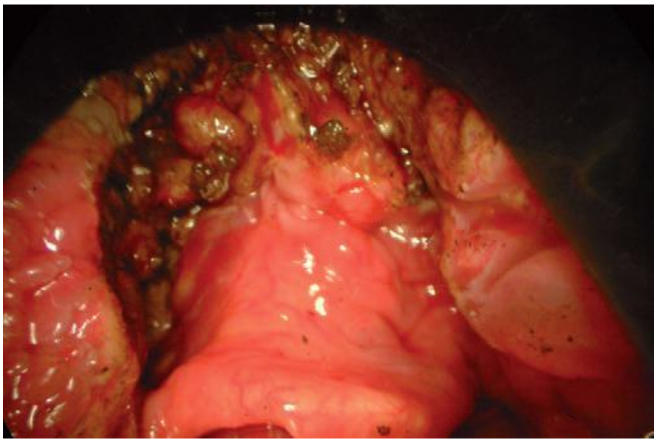

Fig. 1b. Postoperative view following CO_2 laser surgery.

For patients who have mild to moderate disease of the lingual tonsils and can tolerate intraoral manipulation (minimal gag reflex), initial surgical therapy consists of CO_2 laser ablation using a pharyngeal handpiece with mirror tip. More advanced hypertrophy can be ablated with a CO_2 laser fibre (waveguide) passed through a flexible bronchoscope and coupled to the CO_2 laser. These procedures can be performed in the office setting in one or more sessions, depending on the severity of the disease. They can be carried out under topical and local anaesthesia.

In patients who have severe lingual tonsillar hyperplasia with associated obstructive sleep apnoea (OSA), or those with low tolerance to intraoral manipulation, laser surgery is carried out in the operating theatre under general endotracheal anaesthesia. The use of suspension microlaryngoscopy with the newly developed lingoscope (Supraglottoscope) provides superior exposure and haemostatic control in cases requiring extensive resection at the tongue base.

4. Procedures

4.1. Endoscopic ablation of lingual tonsils with a CO_2 laser fibre (waveguide)

The procedure is performed in an office/ambulatory setting using local and/or topical anaesthesia. An operative adult flexible bronchoscope (4.2 mm) with a 2.2-mm working channel is used for this procedure. After the nasal cavity has been topically anaesthetised and decongested, the flexible bronchoscope is carefully passed through the nasal passage to the level of the tongue base. When the lingual tonsil has been visualised, the CO_2 laser fibre (waveguide) is passed through the working channel until it is seen at the tip of the bronchoscope. A video camera/TV monitor set-up aids in better visualisation of the surgery. Anaesthesia of the tongue base is achieved with a topical 4% xylocaine spray followed by local infiltration of the lingual tonsils with 1-2 ml 1% xylocaine with epinephrine (1:100,000). The injection is performed either with a curved indirect laryngeal needle or a modified sclerotherapy needle introduced through the working channel of the flexible bronchoscope (Sharplan Lasers Inc., Allendale, NJ; patent pending). The CO_2 laser is set at 10-15 watts, in the superpulse continuous mode. Only 70-80% of the actual laser energy is transmitted through the laser fibre. The rest dissipates to the fibre wall as thermal energy. A constant stream of air flows through the fibre to keep it cool and clean.

Ablation of the lingual tonsils primarily involves contouring the cobblestone tonsil surface (Fig. 2) in order to achieve a smooth and level configuration, which effectively reduces the size of the lingual tonsil. In chronic lingual tonsillitis, crypts are often present on the tonsillar surface and serve as a nidus for infection (Fig. 3). Surgery is aimed at lasing these crypts. Care is taken to only resect lymphoid tissue, sparing the underlying muscle layers, and thus minimising bleeding. Retracting the tongue forward enhances surgical exposure. This is accomplished with aid of a surgical assistant or with the help of the patient. The patient is asked to exhale slowly during the lasing in order to expel the laser plume. The procedure lasts for ten to 15 minutes and is well tolerated by the patient. At the end of the procedure, an oral rinse of H_2O/H_2O_2 mixture is given to the patient. The patient is observed for one to two hours postoperatively, before being discharged. Postoperative care includes hydration, humidification, analgesia, and antibiotics for five days.

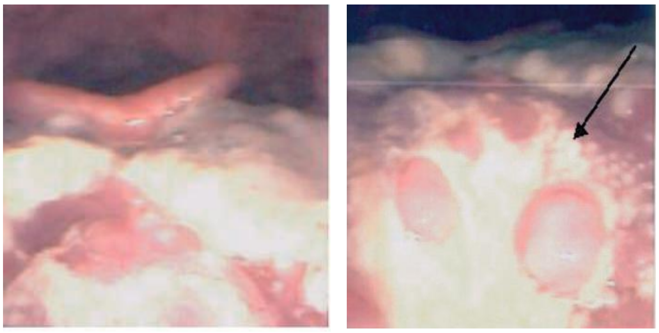

Fig. 2. 'Cobblestone' hypertrophy of lingual tonsil.

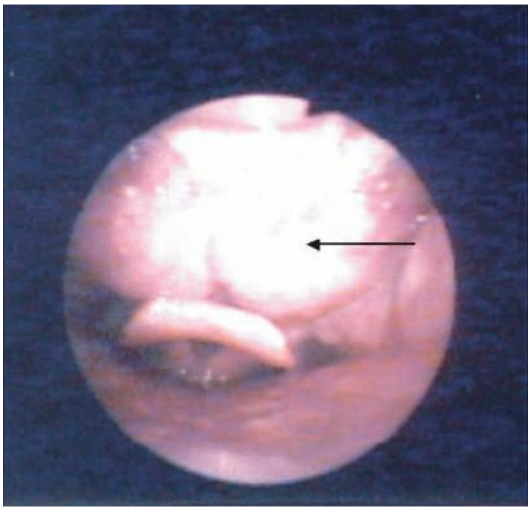

Fig. 3. In chronic lingual tonsillitis (arrow), crypts are often present on the tonsillar surface and serve as a nidus for infection.

4.2. Transoral ablation of lingual tonsils using a CO_2 laser coupled to an operating microscope

This procedure is performed under general anaesthesia with the use of a laser-safe endotracheal tube.

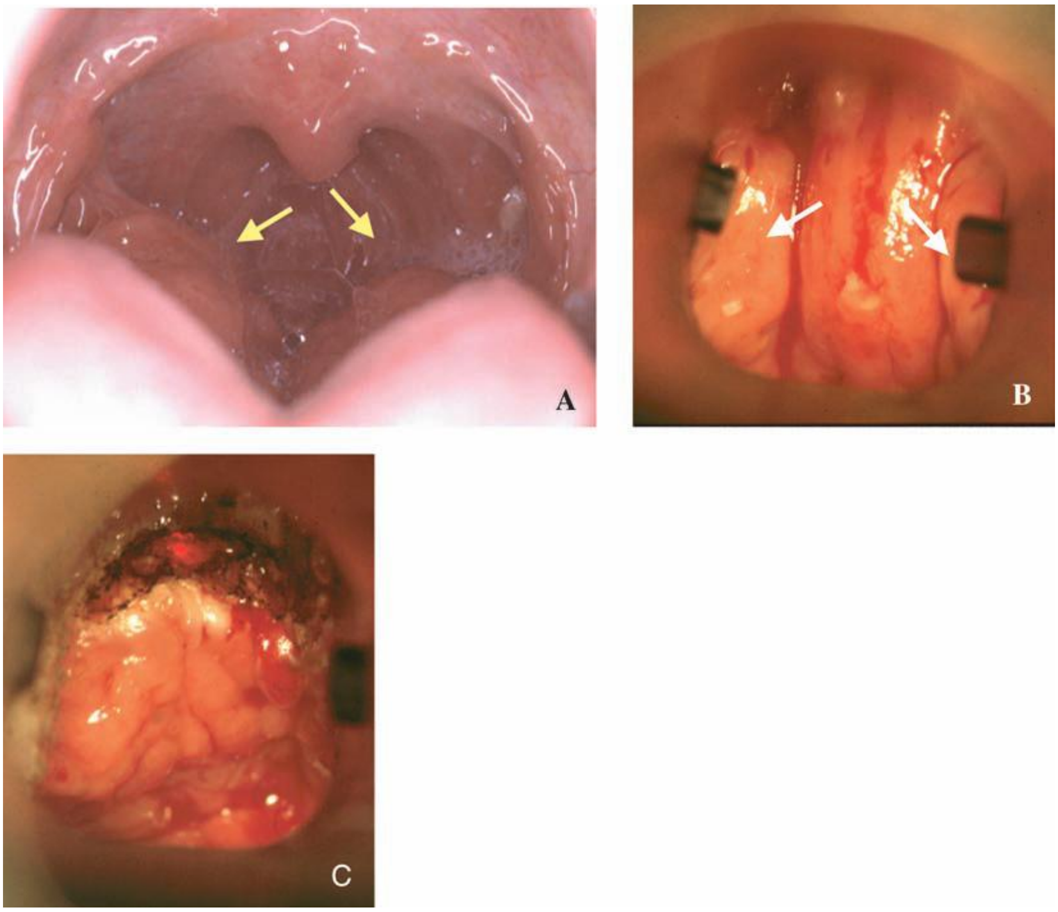

Fig. 4. A, B, C. Massive lingual tonsillar hyperplasia. It is of extreme importance to ablate only the lymphoid tissue, sparing the underlying muscle layers to avoid the risk of troublesome bleeding. The central portion of the tongue base (median glosso-epiglottic fold) is best left intact (photography, courtesy M. Remacle).

A wide-mouth laryngoscope designed for laser surgery is best suited to providing adequate exposure of the tongue base and vallecula. The Supraglottoscope or lingoscope (Richard Wolf Medical Instruments, Vernon Hills, IL) is ideal for this purpose. This scope has a much shorter blade compared to the conventional laryngoscope, and can be adjusted independently for greater control and exposure. The lingoscope is positioned and stabilised with a Lewy suspension holder. Only one side of the tongue base can be exposed at any one time. Once the ablation is completed, the lingoscope has to be repositioned to treat the contralateral side. The newly developed SwiftLase flash scanner (Sharplan Laser Inc., Allendale, NJ) is ideal for ablating the lingual tonsil (Krespi, 1993; Slatkine and Krespi, 1994; Krespi and Ling, 1994). It is of extreme importance only to ablate the lymphoid tissue, sparing the underlying muscle layers in order to avoid the risk of troublesome bleeding. The central portion of the tongue base (median glosso-epiglottic fold) is best left intact (Fig. 4). The laser power setting used for ablation is 12-15 watts in the continuous focused mode when using the SwiftLase flash scanner. In the absence of the SwiftLase, the power can be increased to 15-20 watts in continuous defocused mode in order to cut and coagulate the tissues simultaneously. The lingoscope has a built-in smoke evacuation port which is attached to a smoke evacuator for removal of the plume. Rarely, if bleeding is encountered, the laser beam in the same power setting can be changed to a defocused mode for coagulating small vessels. Persistent bleeding from larger vessels may require electrocauterisation using the conventional suction cautery device.

Patients are often observed overnight in the hospital setting on continuous pulse oximetry. If limited surgery is performed, patients can be discharged the same day. Postoperative care includes analgesics, humidification, hydration, and antibiotics.

5. Conclusion

Diseases of the lingual tonsils can present with a variety of symptoms. They can be broadly categorised into chronic lingual tonsillitis or tonsillar hyperplasia. The pathogenesis of these diseases has been well described by many authors. The mainstay of treatment still remains nonsurgical, and includes oral antibiotics, anti-reflux treatment and allergy therapy. Only when optimal medical therapy fails to alleviate the symptoms should surgical intervention be sought. The reluctance to pursue surgical therapy prior to the advent of the CO_2 laser was due to the morbid complications associated with sharp surgical dissection. These include massive haemorrhage, damage to the surrounding tissues, and potential airway compromise as a result of postoperative oedema. The CO_2 laser has revived the waning interest in performing lingual tonsillectomy. The CO_2 laser beam, directed through a sand-blasted and non-reflective laryngoscope under microscopic control, provides an effective operative alternative to traditional methods. More recently, the CO_2 laser fibre (waveguide) has further expanded the role of the laser in treating lingual tonsils in the office setting under local anaesthesia. Careful patient selection is critical for ensuring success with these surgical techniques. The CO_2 laser seems to be a safe and effective surgical tool for eradicating disease within the lingual tonsils.

Remacle *et al.* (1994) reported their clinical experience in the management of 100 patients suffering from chronic lingual tonsillitis. The CO_2 laser was used at 10-15 W in a slightly defocused mode (spot size 700 µm, at a working distance of 400 mm). The tissue was vaporised until the lingual fascia was reached. In this series, these authors report one instance of postoperative bleeding. There was no incidence of postoperative respiratory compromise. Eighty-seven patients were symptom-free following surgery, 12 did not improve, and in one patient the symptoms worsened.

In common with many surgical procedures, new technology has also made inroads in the management of lingual tonsils. Barakate *et al.* (2008) proposed switching from CO_2 laser to powered instrumentation under videolaryngoscopy. Haemostasis is achieved by bipolar forceps, suction diathermy, or a 5mm endoscopic ligaclip. However, they lack comparative evidence, nor is there any comparative study of different techniques of lingual tonsillectomy in the relevant literature.

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MCQ – 47. Laser management of the lingual tonsils

1. Surgery for lingual tonsils is not commonly carried out because
    a. The access to the surgical site is poor
    b. There is a considerable risk of troublesome bleeding
    c. There is a possibility of respiratory compromise
    d. Its pathology is usually amenable to medical treatment
    e. All of the above

2. CO_2 laser is most useful because
    a. It is possible to undertake rapid vaporisation with SwiftLase flash scanner
    b. It has a deep penetration and therefore large sized blood vessels are effectively coagulated
    c. It can be delivered to the operation site via *silica* optical fibre and used with operative adult flexible bronchoscope
    d. It can be delivered through waveguide although much energy is lost in transmission and gas cooling is required
    e. None of the above

3. CO_2 laser surgery for lingual tonsil hypertrophy
    a. Is effective in controlling most of the intraoperative bleeding
    b. Requires close monitoring because it is usually associated with postoperative oedema requiring steroids
    c. Requires a laser safe anaesthetic tube for general anaesthesia
    d. Can be undertaken both under local as well as general anaesthesia
    e. Under local anaesthesia, sedation is necessary in anxious patients

Chapter 48

Laser ablation of biofilm-loaded tonsillar crypts with tonsilloliths

J. Krespi, M. Remacle and V. Kizhner

1. Introduction

Tonsilloliths (TL) have been a source of scientific debate for a long time. Due to their calcium deposits, the focus remained solely on their mineral component. Any associated infection was considered to be due to dead bacteria and inefficient evacuation of inflammatory products, providing nidus to their formation. Most reports dwelt on their size (up to 44 gram reported) and associated symptoms. It was not until Stoodley *et al.* (2012), provided conclusive evidence that TL were similar in architecture and behavior to dental biofilms.

Biofilms are organised heterogeneous microbial communities. Bacteria can adhere to solid surfaces and produce a slimy, slippery coat with structured features. The resulting adherent mass is referred to as a bacterial biofilm.

The formation of biofilm occurs in multiple stages. First, the bacteria attaches to a convenient, and usually wet, surface. Maturation of the biofilm occurs as bacteria grow into organised three-dimensional structures. Finally, during mature phase, the biofilm may detach, disperse, or embolise, and follow the same cycle in adjacent or distant areas. Confocal microscopy of TL extracted prior to tonsillectomy showed that they consisted of densely packed bacteria including rods, cocci, and filamentous bacteria held together within an extracellular matrix, forming a corncob structure that is not much dissimilar to dental biofilms. Thin slide histology proved that, during the early stages of TL formation, the biofilm was found to be adherent to epithelium of the tonsillar crypt. At high magnification the TL were composed of a dense matrix and large quantities of microbial colonies composed of rods and cocci.

Microelectrodes were inserted in various depth of the TL. The formation of an oxygen profile with anaerobic regions within the TL was assumed to be indicative of aerobic respiration; whereas, acid production was indicative of acid fermentation. The production of N_2O was indicative of de-nitrification. The result showed that the TL consumed oxygen and displayed a pH drop. Aerobic respiration was maximal in the surface layer, down to a depth of 125 μ. De-nitrification was greatest between 50 μ and 200 μ; and acid fermentation occurred predominantly at depths greater than 100 μ. Thin histology sections revealed that the TL was polymicrobial in nature, containing a high density of diverse stratified bacteria. This overall response was similar to that observed in dental biofilms.

The current antibacterial treatment modalities often require a hundred- or a thousand-fold antibiotic dosage to be effective. Such high dosage is inadvisable because of toxicity. The data described above suggested that mechanical, optical, and/or chemical strategies developed to control dental biofilms might be considered for potential treatment of TL.

The biofilm degradation achieved with water pick, commonly used in oral and tonsillar lavage, is thus an effective, non-antibiotic treatment. Each adult palatine tonsil has an average of 10-20 crypts. They appear as fissures on the surface of the tonsil. Each enclosed crypt becomes an anaerobic environment for biofilm formation, which subsequently leads to TL formation in grooves, depressions and cryptic pockets rather than on the tonsil surface.

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Prevention of biofilm formation is perhaps the best strategy. Laser tonsil cryptolysis (LTC) where the CO_2 laser opens the crypt ostium and allows easy clearing of the cryptic pocket is an effective prevention strategy. The stretching and tension of scar tissue around the crypt with the superficial coagulation and contraction are similar to those observed in laser skin resurfacing. The tissue vaporisation leading to consequent reduction of tonsillar parenchyma results in opening of the crypt.

The TLs are directly linked to halitosis as well. Therefore, LTC can reduce halitosis. Halitometry was performed before and after CO_2 laser cryptolysis. It showed reduction of volatile sulphur compounds by 30%. Similar results were corroborated later by Finkelstein *et al.* (2004) who performed CO_2 laser cryptolysis as an office-based procedure with halitosis reduction. The overall number of procedures needed were 1.4 per patient.

A method of discovering TL was described with a clean gloved tonsillar massage and smelling of the glove.

The laser action caused only epithelial coagulation, weakening the tension forces in the crypt borders resulting in their marsupilisation and exteriorisation.

2. Laser choice

While the choice of a CO_2 laser with a scanner is perhaps more accurate and effective for a quicker ablation, a CO_2 laser for the office is a high fiscal burden. A small diode laser may be an alternative device for limited use in treating one or two cryptic areas. Sedlmaier *et al.* (2010) compared the CO_2 laser with a diode laser in a group of 183 paediatric tonsillotomies. The results showed similar pain scores in both groups. There were no post-operative complications such as bleeding or significant pain. Furthermore, laser tonsillectomy potentially offers an advantage over standard tonsillectomy when pain, intra-operative haemostasis, post-operative bleeding and inflammatory reaction is concerned as suggested by Jiang's study (2008). Another confirmation for minimal complication comes from Eisfeld's study (2010), who observed 181 partial tonsillotomies performed with CO_2 laser. In his observation post-operative bleeding was 0%, recurrent infection was 3%, with a follow up period of six years.

Based on these studies, the authors performed a review of a large series of office-based laser ablation of the tonsillar crypts. The study addressed a compilation of the indications mentioned earlier for cryptolysis: halitosis, TL formation and chronic cryptic tonsillitis. The outcome measure was on safety, effectiveness and rate of complications of LTC.

3. Examination

An alternative, more accurate method of examining the tonsils and tonsilloliths is suggested for finding imbedded tonsilloliths. The gag reflex is assessed by palpation of anterior pillars after local spray of 20% Benzocaine. When tonsilloliths are sought, a two hand technique using two wooden tongue blades are used. One spatula gently depresses the tongue, while the other presses the upper border of the anterior pillar (palatoglossal fold) vertically and laterally pushing the tonsil medially and gently squeezing its contents. The tonsilloliths are hidden from view, particularly at the upper pole behind the anterior pillar. The caseous tonsillolith material is examined for an offensive smell confirming the source of halitosis. Patient satisfaction and grading of halitosis was performed on some patients with the Halitosis-Associated Life-quality Test (HALT) questionnaire, which was recently introduced by one of the authors (VK).

4. The selection criteria

The selection criteria were: patient cooperation, tonsil size < +2, controllable gag reflex and ability to adequately visualize and explore the oropharynx in the office. The exclusion criteria were: large tonsils with tonsillar tissue extending beyond the posterior pillar, hyperactive uncontrolled gag reflex and uncooperative patient. Patients with significant tonsil hypertrophy were not considered suitable candidates, we usually excluded patients when the tonsils expanded medially, medial to the posterior pillar, obstructing the view of the palato-pharyngeal fold.

5. Surgical technique

The patient is in a sitting position. Under local anaesthesia, the CO_2 laser with the flashscanner is used to vaporise tonsillar tissue until all the crypts are 'exteriorised'. A two-mm diameter beam at 18 watts in the continuous mode (cw) is used like a paint brush on the surface of the tonsil. The procedure is quick and does not cause much discomfort to the patient. The patient can resume his/her daily life soon after the procedure.

5.1. Laser-assisted tonsil ablation

This is an extension of the cryptolysis technique and is mainly considered for adults. The main indication is chronic tonsillitis, but without peritonsillar abscess. The aim is to vaporise as much tonsillar tissue as possible, but without dissecting it from the base. Under local anaesthesia, subtotal vaporisation of the tonsil is undertaken in one, two, or a maximum of three sessions. Ablation of the upper corner of the anterior pillar to expose the superior pole of the tonsil enables complete identification of new crypts filled with tonsilloliths. A complete one-stage procedure is possible under a general anaesthetic.

Local anaesthesia is given using a spray (lidocaine 10%) and, if necessary, infiltration of the anterior pillar with a few drops of lidocaine and adrenaline. Anxious patients may need sedation. The parameters are the same as those for cryptolysis. The procedure is considered complete when the crypts are completely vaporised and when a smooth surface has been obtained. In case of huge hypertrophy, complete vaporisation of the crypts is difficult to accomplish in one session. In these cases, evaluation takes place at the review examination and further sessions advised, as necessary.

Pain is much less, morbidity extremely low, and recovery much quicker than after complete conventional tonsillectomy.

There is almost no risk of bleeding because the vessels in the base of the tonsil are spared. However, monopolar electrocautery should be available. Depending on the size of the hypertrophy, the procedure may take between 20 and 30 minutes. Postoperative care includes periodic mouthwashes (one-third amylocaine, one-third methyl prednisolone, and one-third an antimycotic drug), paracetamol, and cold and soft diet (no salty or spicy food) for four to five days.

6. Risk and benefit issue

Laser-assisted tonsil ablation is a much simpler method for the management of adult patients who complain of recurrent sore throat and halitosis. It can be carried out as an outpatient procedure in most patients. Usually just one single procedure of cryptolysis is all that is necessary to produce a satisfactory result and the need for full conventional tonsillectomy is negligible.

Complication rate is practically negligible. Intraoperative bleeding is rarely encountered. The procedure is much less painful than conventional tonsillectomy and the morbidity is low. Patients can resume their daily activity much more quickly than after conventional complete tonsillectomy. There was significant reduction on HALT scores. Very few patients need a complete tonsillectomy.

Patient satisfaction is high as the estimated work loss was usually zero and in any case, no more than two days, a factor crucial to working adults.

7. Conclusion

About 40% of TLs are hidden at the time of examination, and only the afore-mentioned method can locate them. There is no correlation between tonsil size and TL formation or its size. This method of examination produces much less gagging from the patient`s perspective. Direct visualisation allows the identification and partial extraction of TL, giving the surgeon a clearer plan for the procedure by exteriorising the crypts and revealing hidden biofilm-loaded crypts resulting in better identification of areas that need to be addressed.

The conventional one-hand method of examination of tonsils with a tongue depressor cannot reveal the hidden TL in the crypts. By calculating the volume of the exposed tonsil on photographs taken with and without the current method of examination, we estimated the additional volumetric gain up to 250%.

LTC is therefore a viable option for the selective group of adult patients suffering from chronic tonsillitis with cryptic tonsils, tonsilloliths and halitosis.

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MCQ – 48. Laser ablation of biofilm-loaded tonsillar crypts with tonsilloliths

1. Each adult palatine tonsil has
   a. Very few crypts
   b. Variable number of crypts depending on patient's age
   c. An average of 10-20 crypts.
   d. An average of 5-10 crypts.
   e. No crypts since it is usually not enlarged in adults

2. Tonsil related halitosis is due to
   a. Formation of tonsillolith in the crypts
   b. Formation of biofilm lining the crypts
   c. Low grade infection due to lack of drainage of crypts
   d. Both, presence of biofilm and tonsilloliths
   e. Poor dental hygiene

3. Cryptolysis is contraindicated when
   a. The tonsil is grossly hypertrophied
   b. When full exposure of tonsil is not possible
   c. When the patient has active gag reflex
   d. When halitosis is not present
   e. All of the above

4. Laser assisted tonsil ablation is indicated when
   a. There is a large number of small tonsilloliths
   b. The tonsils are cryptic, without tonsillolith
   c. The patient has recurrent tonsillitis
   d. The patient complains of halitosis
   e. The tonsil is grossly hypertrophied

5. A preferred method of examination for ascertaining the presence of tonsil stones is:
   a. Asking the patient to open the mouth and say 'AA'
   b. By endoscopic trans-oral fibre optic examination
   c. By palpating the tonsils
   d. By two hand examination, pressing the tongue and lateral wall

Section VII: Snoring and Sleep Apnoea

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Chapter 49

An overview of the management of snoring and obstructive sleep apnoea

B. Kotecha

1. Introduction

The use of lasers in surgery for snoring and obstructive sleep apnoea (OSA) is now a widely accepted modality. This chapter takes an overview of the current practices in the management of these disorders and describes the application of robotic technology as an emerging trend. Other chapters cover surgical procedures related to specific anatomical areas involved in snoring and OSA.

Sleep-related breathing disorder is essentially a spectrum of clinical entities ranging from primary or simple snoring at one end to severe obstructive sleep apnoea at the other end (American Sleep Disorders Association, 1997). The prevalence of snoring in middle-aged men is in the range of 25-50% (Straddling *et al.*, 1991), whereas OSA affects two to four percent of males and one to two percent of females (Young *et al.*, 1993). Sleep disordered breathing may have medical sequelae that affect both the individual and his or her family. Simple snoring may be a source of social embarrassment and marital disharmony. However, when severe, it can be loud enough to cause frequent awakening and disruption of sleep with subsequent daytime somnolence. In patients with OSA, the negative intra-thoracic pressure required to overcome anatomical upper airway obstruction results in severe morbidity such as cardiac arrhythmias, systemic and pulmonary hypertension and myocardial infarction, and, in some cases, even mortality (Guilleminault *et al.*, 1983; He *et al.*, 1988). Furthermore, untreated OSA can also lead to increased incidence of type 2 diabetes, cerebrovascular accidents and road traffic accidents (Ip *et al.*, 2002; Yaggi *et al.*, 2005; George *et al.*, 1987).

The management of snoring and obstructive sleep apnoea requires a multi-disciplinary approach. The various medical disciplines involved in managing these patients include respiratory physicians, otolaryngologists, maxillofacial surgeons, dentists and orthodontists. Broadly speaking, the treatment modalities for snoring and OSA can be divided in to surgical and non-surgical modalities. This chapter will predominantly deal with the former. In particular the emphasis will be on the role of lasers in surgical intervention for upper airway surgery.

2. Presentation

Snoring and OSA are entities contained within a broad spectrum of symptoms and patients suffering from either condition may present themselves to either a respiratory physician or an otolaryngologist. The presenting symptoms are wide ranging, and consist of: loud crescendo snoring, fragmented sleep, daytime sleepiness, morning headaches, reduced libido and impaired cognitive function. The relatives may report apnoeic episodes. The symptoms are worse in supine position, and are exaggerated by intake of alcohol and obesity.

3. Clinical assessment

Clinical assessment undertaken while the patient is awake cannot precisely identify the true nature and

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the site of the obstruction, responsible for snoring and OSA. Nevertheless, it yields considerable information of clinical importance, and every effort should be made to establish a protocol of assessment and record it.

Clinical assessment begins with an Epworth sleepiness score; a score greater than ten is indicative of significant deviation from normal (Johns, 1991). General observation is made of any obvious morphological features such as retrognathia, dental mal-occlusion, neck collar size and Body Mass Index (BMI).

A systematic evaluation of the upper airway is necessary to identify any obstructive anatomical abnormalities contributing to the turbulent airflow. The tip of the nose is lifted with the thumb to ascertain inspiratory alar collapse. Each nostril is then examined with Thudicum speculum to identify the presence of constriction of the nasal valve and caudal dislocation of the septum, easily missed by a rigid or flexible endoscope.

A rigid endoscopy allows a more comprehensive evaluation of the nasal passages and will identify conditions such as deviated nasal septum, nasal polyps and rhinosinusitis. The confirmation of these pathological features is important since their presence will contribute to the failure of compliance and relief from the use of nasal continuous positive airway pressure (nCPAP).

Simple oropharyngeal examination assesses the size and grading of palatine tonsils, the length of the soft palate and the uvula, and also the more subtle features such as redundant pharyngeal folds. A number of clinicians put a considerable emphasis on the Friedman (2002) tongue position and Mallampati (1985) grading in determining if the palatal surgery is indicated in a particular individual. For example, palatal surgery is unlikely to be successful in patients with Friedman tongue position III or IV (Figs. 1 and 2). In contrast, Friedman tongue position I (Fig. 3) would yield better results following palatal surgery.

While of practical importance, Friedman tongue position and Mallampati grading alone is not sufficient since these assessments are done during awake conditions, and may not reflect the true state of the upper airway during sleep, since, there must undoubtedly be some variation in the muscle tone during different phases.

The single most useful instrument in assessing the upper airway is the flexible fibreoptic nasopharyngoscope, which is widely available and allows

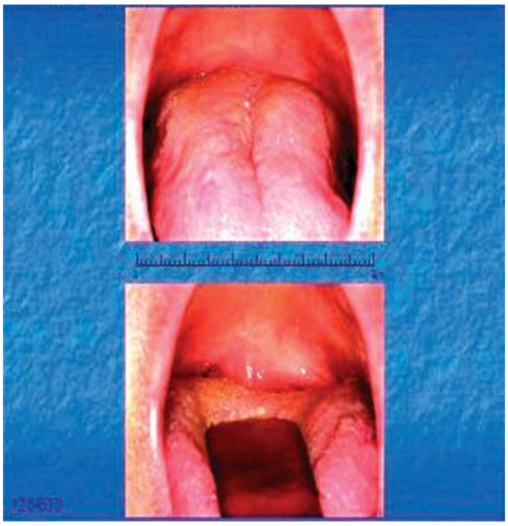

Fig. 1. Friedman tongue position III.

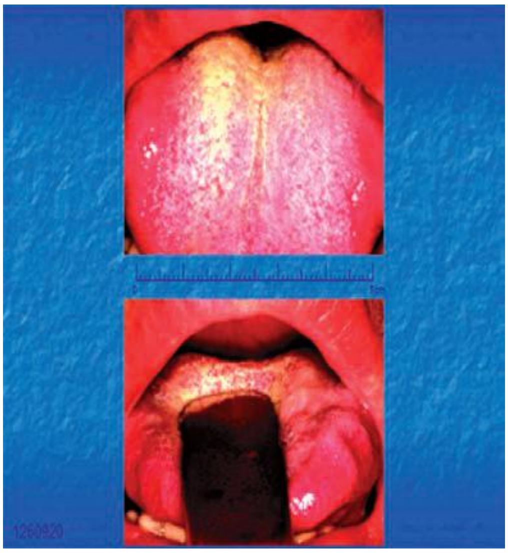

Fig. 2. Friedman tongue position IV.

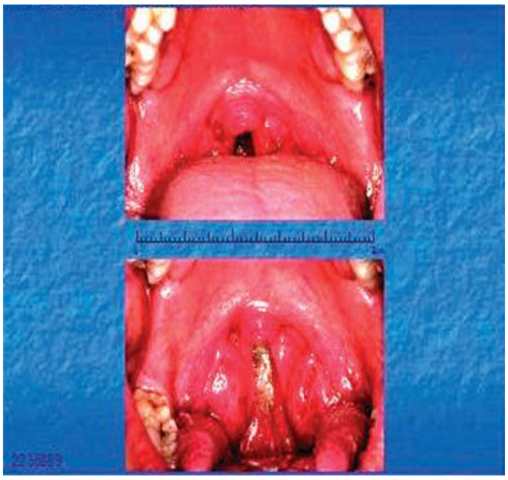

Fig. 3. Friedman tongue position I.

excellent visualisation of all aspects of the naso-, oro- and hypo-pharynx. The patient is asked to simulate a snoring sound so that an area of obstruction can be localised.

Another commonly used technique during the flexible endoscopic assessment is the Müller's manoeuvre. Müller's manoeuvre is the reverse of Valsalva manoeuvre. After a forced expiration, an attempt at inspiration is made with closed mouth and nose. This results in collapse of the upper airway and the trachea, thus identifying an obstruction below the level of the palate. Patients with a positive Müller's manoeuvre test results are unlikely to benefit from uvulopalatopharyngoplasty alone. Of course, Müller's manoeuvre test is carried out in awake patient, and thus cannot represent precisely the site of obstruction during sleep.

4. Special investigations

Computerised tomography (CT) and Magnetic resonance imaging (MRI) form an integral part of special investigation and contribute significantly to localise the site of obstruction.

In order to establish if the patient is suffering from OSA or not, it is vital to arrange either a full, hospital based polysomnography or an ambulatory home sleep study. Simple pulse oximetry may be useful but is not always reliable as some patients with OSA may be missed (Overland *et al.*, 2002).

Sleep nasendoscopy (SNE), also known as drug induced sedation endoscopy (DISE) was pioneered at author's institute (Croft and Pringle, 1991). Drug induced sleep is different from natural physiological sleep and may have a tendency to exaggerate muscle relaxation. Nevertheless, assessed segmentally, it provides a comparative *contributory* information in respect of each anatomical region, not significantly dissimilar to the one that exists in natural sleep.

Sleep nasendoscopy is carried out in an operating theatre setting. The anaesthetist induces sleep under sedation with midazolam or propofol, or both.

Acoustic analysis and pressure transducer measurements may be useful, but are not strictly necessary. Some routine haematological investigations are also carried out to rule out anaemia and underactive thyroid gland which can cause daytime sleepiness.

5. Treatment options

In all patients, any aggravating factors such as weight loss, reduction in alcohol intake and improved sleep hygiene should be addressed with an advice on life style changes. Contributory nasal pathology should also be suitably managed.

Non-surgical treatment may be preferred by many individuals. It is now generally accepted that patients suffering from moderately severe or severe OSA should be offered nCPAP as the first line treatment (NICE, 2008). Mandibular advancement devices may also be offered to patients who wish to avoid surgery. However, acceptance and compliance of using appliances for the rest of their lives is not universally appealing and therefore surgery provides a useful option in such individuals.

6. Surgical management of snoring and OSA

Surgical management is aimed at corrective surgery to overcome an obstruction, or to bypass it by advising tracheostomy. Corrective surgery includes nasal, oropharyngeal and hypopharyngeal surgical procedures. In addition, hyoid suspension and maxillary-mandibular advancement may also be offered. Surgical philosophy requires a consideration of risk benefit issue, in full consultation with the patient and the relatives. Elshaug *et al.* (2008) criticised the enthusiasm for surgical interventions.

6.1. Palatal surgery

Of all the surgical intervention for snoring and obstructive sleep apnoea (OSA), palatal surgery is by far the most commonly performed surgical procedure. Oro-pharyngeal abnormalities in these patients include enlarged tonsils, elongated uvula, lax soft palate and redundant pharyngeal mucosa.

In some patients, where a minimum intervention is judged to be adequate on account of mild to moderate symptoms, minimally invasive surgical procedure is indicated. It consists of chemical injections or radiofrequency thermotherapy to induce scarring or stiffening, without physical alteration of the soft palate or the oro-pharynx.

In others with more severe problems, a more radical approach is required. It consists of a combination of excision of redundant pharyngeal mucosa, reduction of uvula, and shortening of soft palate, with or without tonsillectomy.

6.2. *Radical palatal surgery*

Palatal resection is indicated in patients who fail to respond to minimally invasive procedures, and in those, who have severe symptoms at presentation. It is also indicated in patients who have failed to get benefit from nCPAP.

Uvulopalatopharyngoplasty (UPPP) was first performed by Ikematsu in 1964 but subsequently many variations of the technique have been reported and the operation was re-popularised by Fujita in the 1980s (Fujita *et al.*, 1981). The general principle of this procedure is to enlarge the retropalatal dimension. Radical UPPP is generally an *extremely* painful procedure associated with high morbidity and unfortunately mortality has also been reported. The complications that raise great concerns are nasopharyngeal stenosis and incompetence. There have also been problems in patients being unable to tolerate CPAP therapy after undergoing radical UPPP. For these reasons more conservative variations of the technique have been introduced and the use of lasers has been somewhat helpful in achieving this.

7. Laser assisted palatoplasty

The laser was first introduced for palatal surgery in the 1980s as a high energy tool with great precision and was utilised in performing laser assisted uvulopalatoplasty (LAUP) under local anaesthesia (Kamami, 1990). Kamami described a technique using CO_2 laser delivered via a specially designed hand-piece with a back stop to prevent inadvertent laser injury to the posterior pharyngeal wall (1994). Subsequently, various other authors have described modifications of the technique and have used other lasers including Nd:YAG, Ho:YAG, KTP/532, Thulium and diode laser. Some lasers are more suited to the *office-based* procedure than others.

Kamami's original description recommended the office procedure under local anaesthesia. Serial procedures were performed at six weekly interval, until the optimum benefit was achieved. However, the extent of soft palate excision was not defined. Kotecha *et al.* (1998) introduced objective method by measuring the length of the soft palate and advocated reduction of up to 25% of the palatal mass. They also advocated a 50% reduction of the uvular length in a single stage procedure performed under general anaesthesia.

Further modification of the 'Kotecha technique' consisted of excision of the redundant posterior pillars without altering the natural palatal contour (Patel *et al.*, 2006). As this technique is more extensive than the Kamami version and the procedure is completed as single stage management, the use of general anaesthesia is indicated.

8. The Kotecha technique

The patient is positioned in the standard tonsillectomy position with appropriately wet drapes paying particular attention to all the laser safety issues described in Chapter 3. A Boyle-Davis mouth gag, adapted with a suction port to aspirate the laser plume, is inserted in to the oral cavity and the oropharynx is widely exposed. Wet swabs are placed in the post-nasal space and in the oropharynx. The swabs protect the posterior pharyngeal wall from inadvertent laser strikes and also make the palate taut.

A microscope mounted CO_2 laser provides a superior view of the surgical site. The power is set at 10 watts, delivered via a micromanipulator. It allows precise control via a standard joystick. If tonsillectomy is also planned, it is performed first. However, it is not necessary to remove the whole tonsil if there is no history of infective episodes. The bulk can simply be reduced by undertaking serial or subtotal tonsillotomy (Chapter 46).

The soft palate is measured from the hard/soft palate junction to the free edge and 25% of this length is marked (Fig. 4). Similarly, the length of the uvula is noted and a 50% mark is made (Fig. 5).

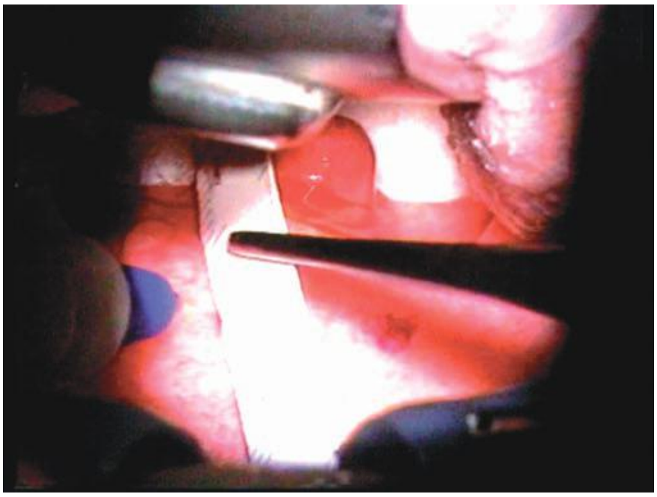

Fig. 4. Measurement of the soft palate with swabs in the post nasal space.

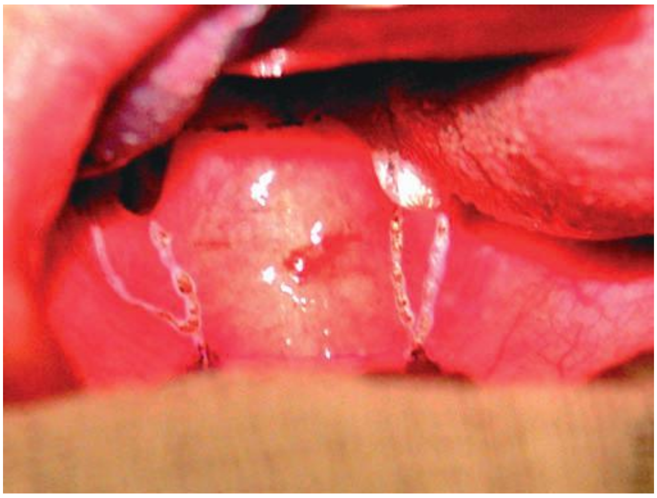

Fig. 5. Laser marking on soft palate, posterior pillar and the uvula.

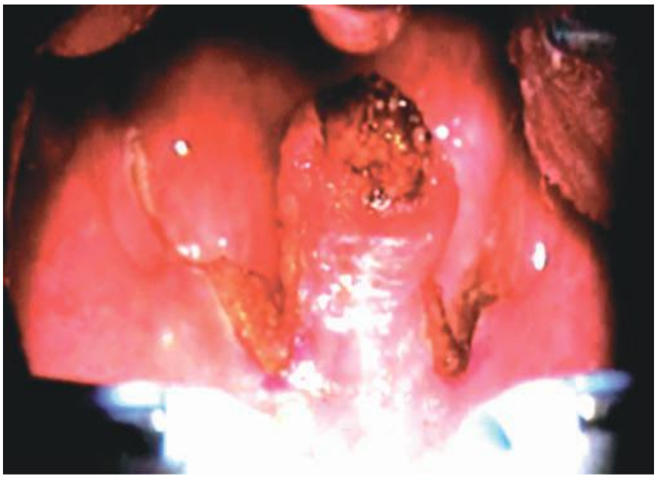

Fig. 6. Appearance after completion of the Kotecha technique LAUP.

Next, bilateral full thickness incisions are fashioned through the mucosa, submucosa and the muscle of the soft palate up to the 25% mark. The redundant posterior pillar on either side is conservatively excised as is the uvula up to the 50% mark. The excision of the uvula is bevelled, so that the posterior surface is longer than the anterior surface. This configuration helps adequate formation of the neo-uvula, maintaining the nasopharyngeal competency (Fig. 6). Sutures are not required as subsequent healing occurs satisfactorily by fibrosis.

An intravenous dose of eight mg of dexamethasone is given intra-operatively and the patient is discharged after four to six hours.

The postoperative course is usually uneventful. Adequate analgesic agents, such as diclofenac sodium together with soluble cocodamol, are prescribed. In some patients, the postoperative pain can be exceptionally severe. Stronger analgesics such as tramadol are necessary to control the pain. Oral intake is encouraged soon after surgery. Maintenance of good oral hygiene is of paramount importance. The first postoperative visit is usually arranged four weeks later. By this time, healing is usually complete.

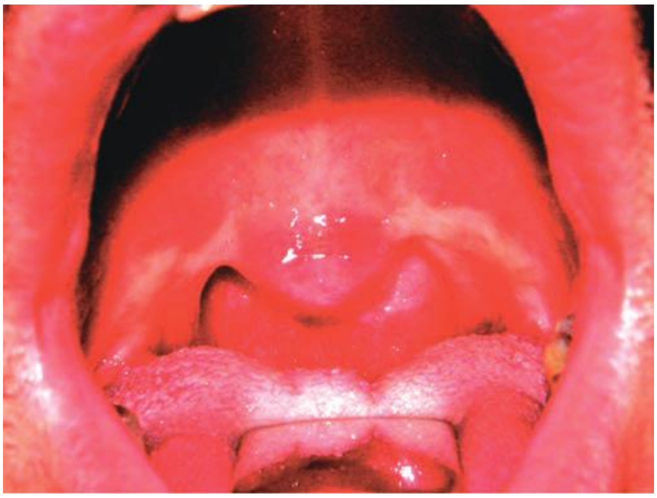

Fig. 7. Postoperative appearance after four weeks.

Some patients experience a sensation of globus. Change in palatal contour may result in alteration in the tonal quality, which may be important in professional voice users, and in some dialects. Postoperative bleeding is rarely encountered, and its incidence is minimised by compliance to oral hygiene regime. The healing is complete two weeks postoperatively while fibrosis continues for a period of further four weeks when final outcome is assessed (Fig. 7).

9. Surgical outcome

Short-term success has been reported universally in carefully selected patient cohort. However, most series also report some deterioration with the passage of time (Walker *et al.*, 1999; Mickelson and Abuja, 1999). Successful outcome for snoring varies from 45% to 80% and for OSA from 30% to 70%. Data interpretation has become somewhat difficult as there is great variation in definition of success. Meta-analysis conducted by Verse and Pirsig (2003) confirmed the difficulty in comparisons, since criteria of success vary considerably in different studies.

The author's personal experience with laser-assisted palatoplasty for snoring and OSA has been encouraging in both short and long term (Kotecha *et al.,* 1998; Iyngakaran *et al.,* 2006). This may be due to our strict patient selection criteria which are based on endoscopic evaluation during sedation-induced sleep. With this investigation we are able to ascertain accurately the level of obstruction and target the specific anatomical site.

Palatal surgery has also been undertaken in highly select group of failed CPAP patients. In these patients, improvement in oro-pharyngeal dimensions leads to a better CPAP compliance (Chisholm and Kotecha, 2007).

10. Transpalatal advancement pharyngoplasty

The UPPP and the above mentioned modifications involve partial resection of the *soft* palate, resulting in an increase of the retropharyngeal dimension. In contrast, transpalatal advancement pharyngoplasty involves excision of the *hard* palate and relocation of the soft palate anteriorly. The bulk of the soft palate remains the same, but its forward position results in an increase of the retropharyngeal dimension (Woodson, 1997). The end result of this procedure is intended to pull the palate forward and superiorly, and is likened to surgery for maxillary advancement. With this technique, excessive scar tissue formation and velopharyngeal insufficiency is less of a problem compared to UPPP. Outcome data on this particular technique is fairly limited; however it appears that it may be usefully performed in some patients who continue to have a narrow retropalatal space in spite of the an anatomically adequate UPPP.

Palatal surgery alone may not be sufficient in resolving the symptoms of snoring and/or OSA and other treatment modalities may need to be used in combination. This may include appliances such as mandibular advancement devices, CPAP or indeed other surgical intervention addressing the nose or the tongue in the typical multi-level obstruction that is often encountered in many of these patients. Palatal surgery nevertheless remains a first line option, and an important component of the surgical armamentarium for snoring and OSA.

11. Minimally invasive palatal procedure

Minimally invasive palatal procedure under local anaesthesia is carried out simply by injecting chemicals into the soft palate. Chemicals cause inflammatory reaction, healing takes place by fibrosis, thus stiffening the palatal tissue. This technique of 'injection snoreplasty' utilises chemicals such as sodium tetradecyl sulphate to stiffen the soft palate (Brietzke and Mair, 2001). This technique is not recommended in patients with OSA and even in simple snorers, the results are not uniform. Any improvement in snoring is short lived. A risk of palatal ulceration and fistula formation exists, but complete resolution is usually achieved in a few weeks, with no long term sequel.

12. Radiofrequency thermotherapy

Radiofrequency thermotherapy has been reported to be beneficial in simple snorers and mild OSA. Monopolar, bipolar and plasma mediated ablation devices (Somnus®, Celon® and Coblation® respectively) are available. Bipolar device avoids mucosal damage and ulceration. Thermal trauma results in inflammatory reaction, which heals with fibrosis. Stiffening and some shrinkage of the soft palate is achieved. The use of radiofrequency is based on much less rise in tissue temperature (80° C) compared to that caused by the laser (300° C). Stimpson and Kotecha (2011) studied palatal tissue effects following radiofrequency and laser usage, with histopathology and scanning electron microscopy. They noted the impact of thermal trauma with the two different surgical tools (Figs. 8-10) at cellular level. With cutting radiofrequency the epithelium was found to be intact, whereas with the CO_2 laser there was shedding of the squamous epithelium.

The treatment can be easily carried out under local anaesthesia. The frequency of interstitial applications depends on the type of device used. When using Somnus®, it is recommended that three to five puncture points are made. When bipolar Celon® is used, up to ten puncture points can be made.

There is no reason why radiofrequency cannot be combined with resection of redundant tonsillar pillars or elongated uvula. It is quite likely that in patients who relapse, multiple treatment applications would be required as there may be some regeneration of elastic fibres following earlier fibrosis. Numerous studies have reported subjective improvement in simple snorers, but objective and long-term data is lacking and in cases of OSA the success rate is disappointingly low. Stuck *et al.* (2004) have summarised the results of effective-

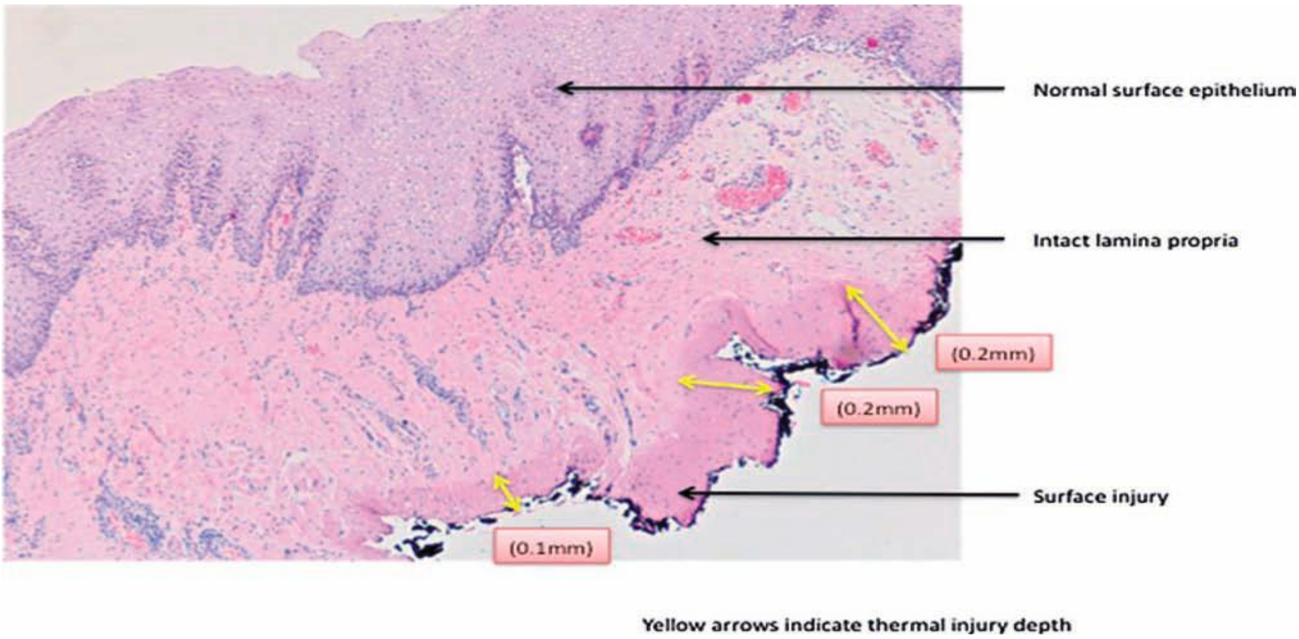
Normal surface epithelium
Intact lamina propria
(0.2mm)
(0.2mm)
Surface injury
(0.1mm)
Yellow arrows indicate thermal injury depth

Fig. 8. Histopathological slide of cut surface of uvula following cutting radiofrequency (H & E stain).

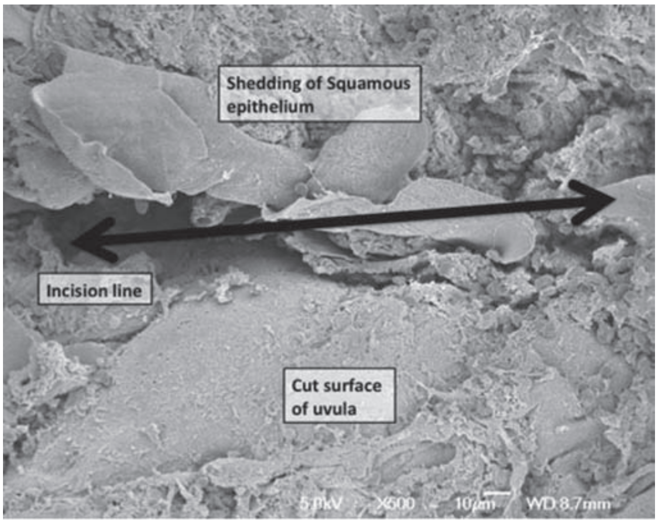
Shedding of Squamous epithelium
Incision line
Cut surface of uvula
5.0kV X500 10μm WD 8.7mm

Fig. 9. Excision margin of uvula following CO_2 laser with shedding of squamous epithelium (scanning electron micrographs).

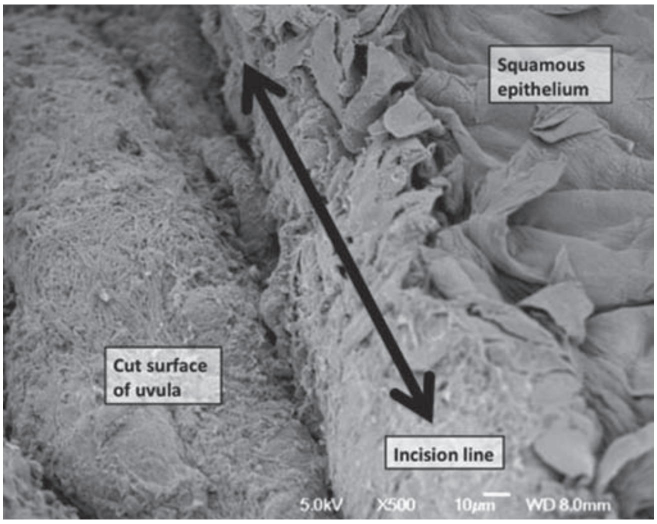
Squamous epithelium
Cut surface of uvula
Incision line
5.0kV X500 10μm WD 8.0mm

Fig. 10. Excision margin of uvula following radiofrequency excision with intact squamous epithelium (scanning electron micrographs).

ness of palatal radiofrequency surgery for simple snoring in 505 patients representing 22 studies. An overall decrease in snoring was seen from 8.2 pre-operatively to 3.7 postoperatively, on a visual analogue scale. The complications encountered with radiofrequency treatment to the soft palate are usually mild and include mucosal ulceration; however mucosal breakdown and fistula formation has been reported.

13. Palatal implant

Ho *et al.* (2004) inserted palatal implant made of polyethylene terephthalate within the soft palate to increase its stiffness and thus reduce snoring. The implant is inserted under local anaesthesia. They report a significant reduction in snoring at three months follow up. The implant did not cause any complications. However, it was rejected in two patients, but without any sequel. Further studies were advocated by the authors, commenting on the simplicity of the procedure. At the time of writing, there is a lack of long-term follow up as well as objective evidence. This technique is of little use in patients with OSA and in theory, should be reserved for simple snorers who do not have large tonsils, pronounced soft palate webbing or elongated uvula.

14. The role of laser in nasal surgery

The nose is the first port of entry for the airflow and nasal pathology can contribute significantly to upper airway obstruction (Kotecha, 2011). Pathology such as deviated nasal septum, nasal polyps and hypertrophied turbinates interferes with normal breathing and results in snoring. Moreover, in OSA patients managed with nCPAP therapy, such abnormalities can interfere with the treatment and reduce the CPAP compliance and efficacy. A novel non-surgical treatment of deviated cartilaginous septum involving office based 'laser reshaping' is described in Chapter 62.

In general, conventional nasal surgery is straight forward and manages to attain fairly good outcomes. Role of lasers in the management of nasal pathology is discussed in Section III.

15. The role of laser in hypopharyngeal surgery

The role of the anatomical configuration of the base of the tongue and the epiglottis in the aetiology of snoring and OSA is usually underestimated, particularly in failed cases of palatal surgery (Kotecha, 2007). In the author's clinical practice, the technique of SNE is found to be particularly useful in identifying the contribution of hypopharyngeal collapse in the snorers. A large mass of the tongue base has an effect of pushing the epiglottis posteriorly, thus reducing the hypopharyngeal dimensions considerably, resulting in snoring and/or OSA (Fig. 11).

In other cases there may be a dual problem, in addition to the tongue base retraction there is epiglottic retraction like a 'trap-door' on to the larynx (Fig. 12).

In these cases, the surgical treatment requires addressing the epiglottis as well as the tongue-base. This topic is further covered in Chapter 54.

The access and exposure of the tongue base and the epiglottis is not always easy in patients with OSA. In addition to the symptoms of OSA, they often pose morphological difficulties such as limited mouth opening and macroglossia. Furthermore, the tissues in this region are particularly vascular, with a potential to haemorrhage and oedema leading to airway compromise.

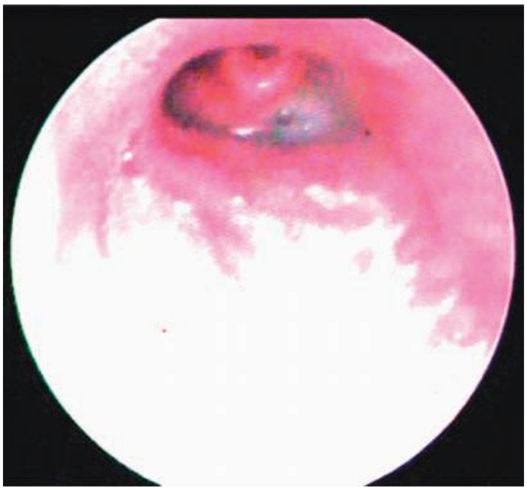

Fig. 11. Tongue retraction pushing the epiglottis to occlude the larynx.

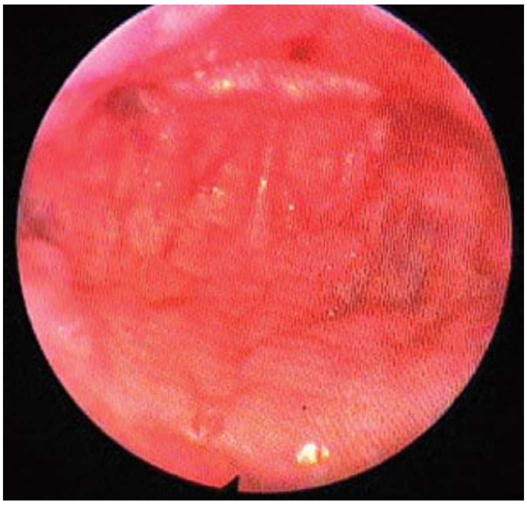

Fig. 12. Epiglottic 'trap door' phenomenon.

The laser is admirably suited for midline glossectomy and/or, in cases of epiglottic 'trap-door' configuration; epiglottic wedge resection. However, many clinicians would advocate a pre-operative temporary tracheostomy to protect the upper airway from potential obstruction due to oedema or haemorrhage in the post-operative period. Woodson and Fujita (1994) recommend a midline rectangular resection measuring approximately two cm wide and four cm long. Problems with dysphagia, odynophagia, dysphonia and aspiration may occur and the involvement of the speech and language therapist is recommended.

16. The role of robotic surgery in snoring and OSA

A recent advance in the surgery in the oral cavity is the introduction of da Vinci transoral robotic approach (Vicini *et al.,* 2010). This approach, along with the use of flexible CO_2 and thulium laser fibres has made the surgery much easier and precise. We have had encouraging early results in a few patients undergoing transoral robotic surgery to the epiglottis and tongue base simultaneously (Figs. 13-16).

We have used the RevoLixJr (Lisa Laser, USA) system emitting at two micron. The beam is transmissible via a flexible 200-micron optical fibre. At two micron wavelength, it causes much less thermal damage and yet attains adequate haemostasis.

The obvious advantages of the telerobotic system include excellent 3-D imagary, immaculate precision and lack of tremor. In our small series (unpublished data), we did not have to perform tracheostomy pre-operatively. The patients were nursed in a high-dependency unit for a few hours after surgery. Before extubation, we routinely perform a flexible endoscopic assessment of the upper airway to ensure that there is no potential to the airway compromise. Robotic surgery is further covered in Chapter 65.

17. Conclusion

An audit of a cohort of 2,485 procedures performed over a period of ten years at our institute demonstrated that there was a significant correlation of SNE with apnoea-hypopnoea index and mean

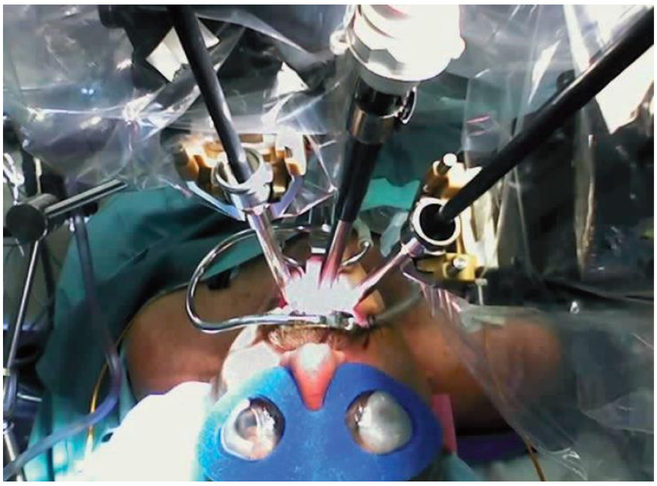

Fig. 13. Transoral robotic set up.

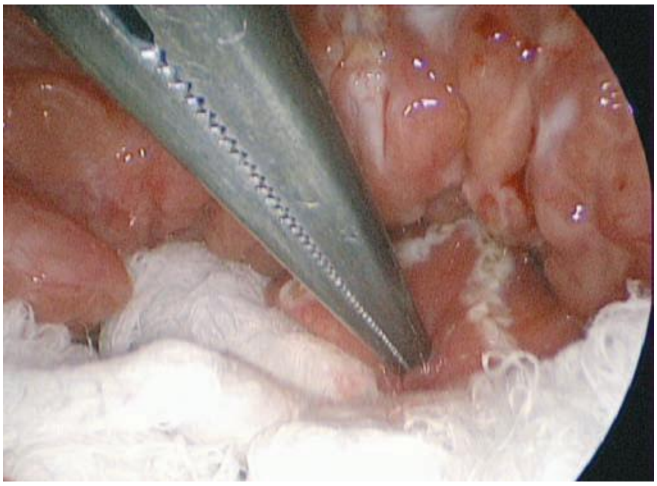

Fig. 15. Inverted ‘V’, marked with a laser in preparation for epiglottic wedge resection.

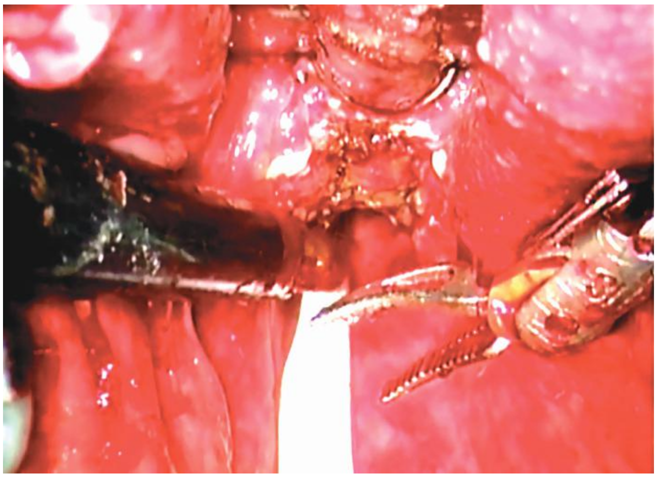

Fig. 14. Robotic instruments in the oral cavity during midline glossectomy.

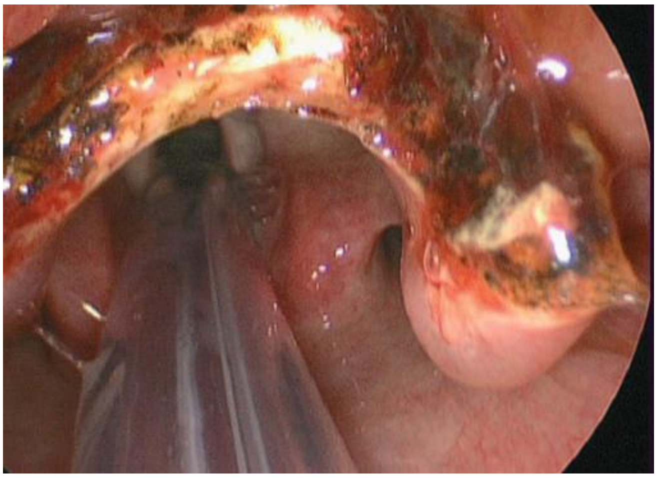

Fig. 16. The clear view of vocal folds at the end of the procedure.

oxygen desaturation (Kotecha *et al.*, 2007). SNE is also useful in predicting treatment success in snorers who were managed with mandibular advancement splint (MAS) (Battagel *et al.*, 2005). Similarly, SNE has allowed targeted site selection in surgical patients with improved surgical outcomes in laser assisted palatoplasty, with or without tonsillectomy (Chisholm and Kotecha, 2007).

In the past couple of decades, laser has come to play a significant role in surgery for snoring and OSA. A wide variety of lasers are available for procedures on the nose, palate, tongue and the epiglottis. The simplest of systems allow easy office-based procedures while the more advanced systems incorporated within the telerobotic system help in the management of complex cases of moderate or severe OSA. Patient selection is of utmost importance and needless to say that laser safety must always be closely observed.

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MCQ – 49. An overview of the management of snoring and obstructive sleep apnoea

1. Snoring and obstructive sleep apnoea (OSA)
   a. Are two separate conditions
   b. OSA is a continuum of long term snoring
   c. Every case of snoring, untreated will proceed to full blown OSA in the long term
   d. OSA symptoms are due to negative pressure generated in the thorax to overcome obstruction to breathing.
   e. Severe snoring episodes are as serious as OSA

2. Every case should have a minimum of the following assessment protocol
   a. General head and neck examination for any obvious morphological features
   b. Thudicum speculum examination
   c. Naso endoscopy
   d. Sleep naso-endoscopy
   e. All of the above

3. Further simple assessment is carried out by
   a. Friedman tongue position
   b. Mallampati grading
   c. Valslva manoeuvre
   d. Muller's manoeuvre
   e. Awake snoring mimicking by the patient

4. Special investigations consist of
   a. AP and lateral views of head and neck
   b. CT and MRI scan
   c. Pulse oximetry
   d. Polysomnography
   e. Sleep naso-endoscopy

5. Drug induced sleep endoscopy
   a. Is done as ambulatory home test
   b. Is done in the operating theatre
   c. Requires general anaesthesia
   d. Sleep induction with drugs administered by the anaesthetist
   e. Has advantages of reproducing exact real time snoring and OSA episodes

6. In every case, management starts with
   a. Adjustments to life style as necessary (alcohol, smoking, weight loss)
   b. Antiallergic medication
   c. A period of trial with nCPAP
   d. Mandibular advancement devices
   e. Thorough patient and partner counselling

7. In majority of simple snorers corrective surgery is usually located in
   a. Palate and uvula
   b. Tonsillar enlargement

   c. Redundant pharyngeal mucosa
   d. Lingual tonsils
   e. Various combinations of the above

8. Kotecha technique advocates

   a. Serial reduction of palatal bulk
   b. Measurement of the length of uvula and 50% reduction
   c. Measurement of soft palate and 25% reduction
   d. Tonsillectomy
   e. Reduction of pillars

9. The main postoperative concern in palatal laser surgery is

   a. Bleeding
   b. Nasal voice
   c. Nasal regurgitation
   d. Pain which always needs active management
   e. Globus sensation

10. Methods other than laser for reduction include

   a. Microdebrider
   b. Diathermy
   c. Radiofrequency
   d. Harmonic scalpel
   e. Palatal implant

Chapter 50

Laser-assisted surgery for snoring and obstructive sleep apnoea

V. Oswal, Y.V. Kamami, J. Krespi, R. Simo, A. Kacker and V. Kizhner

Part A: Literature update

V. Oswal

Some twenty years on since the laser technology was introduced for snoring and OSAS, a number of reports have been published but none of them show a conclusive message that the surgery is successful, unsuccessful or even ill-advised. At best, it is partially successful with a number requiring further procedure. On the other hand, surgery for contributory multi-level obstruction seems to hold promise in reducing their role in overall snoring.

Generally, palatal surgery for snoring and mild OSAS does not show any long term complications or sequel. Postoperative pain is an issue, but is said to be less and also does not last as long, when radiofrequency or palatal implant is used.

The surgical outcome is variously assessed, the frequency of sleep disturbance, the loudness of snoring, the long-term benefit and of course, the bed partner opinion. Repeat surgery can be either electively staged or undertaken to tackle residual snoring. Laser generally causes more extensive tissue destruction and hence postoperative pain and oedema is prolonged. Palatal implants do not have many drawbacks. Office based procedures are common, not in the least due to reduced costs. Initial results show high success but the rate falls with time.

Practice parameters for OSAS were first published in 1996 by American Academy of Sleep Medicine and updated in 2010. These are summarised below, further reading is advisable.

- The presence and severity of OSAS must be determined prior to any surgery.
- The patient should be advised of the potential success rate and complications.
- The patient should be advised of the alternative management strategy such as nPAP or oral appliances and their effectiveness.
- LAUP is not routinely recommended as a treatment for OSAS.
- UPPP as a sole procedure, with or without tonsillectomy, does not reliably normalize the AHI in moderate to severe OSAS
- Tracheostomy is an effective option in all failed cases.
- Postoperatively, patients should undergo follow up evaluation including an objective measure of the presence and severity of sleep-disordered breathing and oxygen saturation, as well as clinical assessment for residual symptoms. Patients should be followed over time to detect the recurrence of disease.

Iyngkaran *et al.* (2006) undertook a retrospective study in a cohort of 469 patients treated variously with LAUP, with associated tonsillectomy and septoplasty as required, The median follow up time was 59 months. A survey population consisted of 168 patients. Interestingly, postoperative weight gain did not show a poorer outcome, nor did postoperative weight loss show a better outcome. The questionnaire survey showed that although the number of patients who experience initial benefit is high, only 55% patients are predicted to enjoy a long-term benefit from LAUP surgery.

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Prasad *et al.* (2003) posed themselves an extremely pertinent question: Are partners satisfied in the long run? After all, an asleep (ex)snorer is hardly going to notice surgical benefit if any! A question based survey with a minimum follow-up of one year included a cohort of 91 procedures (# 50 LAUP and # 41 UVPP). They found that the residual snoring was more frequent with LAUP than with UVPP. However, there was a highly significant reduction in the sleep disturbance and need to wake up after both surgical methods. The report was based on health care provided under social medical system (National health service, UK) where tax-payers money is spent to provide free care at the point of delivery. They concluded that both LAUP and UVPP procedures provided good long term results to justify expenditure.

Main *et al.* (2009) evaluated clinical success and costs of surgical procedure and non-surgical devices in the management of non-apnoeic snoring. Major electronic databases published between 1980 and 2007 provided the material for study. The management strategy in 27 studies was indeed wide ranging, including UVPP, LAUP, palatal stiffening techniques (Pillar implants and injection snoreplasty), radiofrequency ablation (RFA) of the soft palate or tongue base, continuous positive airway pressure (CPAP) devices and mandibular advancement splints (MAS). A total of 1191 patients were included. It is not surprising that their study failed to identify gold standard and at the same time cost-friendly surgical or non-surgical method which could be recommended for primary snoring.

Lim *et al.* (2007) undertook prospective randomised study in a cohort of 44 patients: 20 patients had LAUP whereas 24 were treated with radiofrequency assisted uvulopalatoplasty (RAUP). The surgical outcome measures included subjective degree of snoring, the Epworth sleepiness scale score, the operation time, postoperative pain, episodes of delayed bleeding, globus sensation and scar contracture. They found the operation time was shorter in the LAUP group whereas postoperative pain and postoperative complications (globus sensation and scar contracture) were less in the RAUP group. They concluded that RAUP procedure results in significantly lower postoperative pain, complications and other problems experienced in LAUP, while maintaining the advantages of LAUP.

Belloso *et al.* (2006) reported single blind randomised controlled trial to study postoperative pain following coblation palatoplasty (CP) and laser palatoplasty (LAUP). KTP laser was used in 13 patients to carry out LAUP without tonsillectomy and coblation radiofrequency was used in 17 patients who had both UVPP as well as tonsillectomy. They found that in the first eight days, the pain was similar in both groups, whereas the CP group showed statistically significant reduction in pain after eight days. It is important to note that this study compares two dissimilar surgical scenarios with different energy modes: in the KTP laser group, LAUP alone was carried out whereas in the coblation group, UVPP was undertaken along with tonsillectomy, introducing a number of variables.

Rombaux *et al.* (2003) undertook prospective study in a cohort of 49 patients to evaluate postoperative complication rate and pain. 17 patients had uvulopalatopharyngoplasty (UPPP); 15 had laser-assisted uvulopalatoplasty (LAUP), and 17 had radiofrequency tissue volume reduction (RFTVR). The extent of 'volume reduction' is not specified. Postoperative pain in RFTVR was less than in the other two groups. The UPPP and the LAUP group also showed increased incidence of wound infection, dehiscence, and posterior pillar narrowing. They conclude that the RFTVR is a safer and less painful procedure compared to UPPP and LAUP for the treatment of primary snoring.

Halme *et al.* (2010) studied the efficacy of LAUP intervention in patients with partial upper airway obstruction (mild OSAS) during sleep. The diagnosis of OSAS and its severity was based on a static charge-sensitive bed (SCSB) combined with oxyhaemoglobin desaturation recording and digital fluoroscopy-based collapsibility estimation. In a cohort of 27 patients, LAUP was carried out under local anaesthesia as day surgery. The preoperative investigations were repeated 6 months postoperatively. They found that partial upper airway obstruction events and arterial oxyhemoglobin desaturations during sleep decreased significantly. The anteroposterior dimension increased and collapsibility decreased at the level of the soft palate. Their finding suggest that early intervention by way of UVPP was helpful in curtailing progress of mild OSAS to severe OSAS.

Franklin *et al.* (2009) undertook systematic review of PubMed and Cochrane databases to ascertain the efficacy and adverse effects of surgery for snoring and obstructive sleep apnoea. They concluded that these studies did not provide any evidence of effect from laser-assisted uvulopalatoplasty or radiofrequency ablation on daytime sleepiness, apnea reduction, quality of life or snoring and called for a more research. According to them, randomized, controlled trials of surgical methods other than uvulopalatopharyngoplasty and uvulopalatoplasty are required, since these procedures are related to a high risk of long-term side-effects, especially difficulty in swallowing.

Patient suffering from oral submucous fibrosis have a short and fixed uvula and scarred soft palate. In an interesting study to assess if surgery for snoring really has any sound basis for improvement in sleep related symptoms, Soni AK (1997) studied forty patients above the age of 40 years with oral submucous fibrosis (OSMF). Frequency and severity of snoring was noted. The results were compared with a controlled group of similar sex and age for presence of snoring. The study indicated that OSMF patients, with unyielding and fibrosed soft palate and uvula were less likely to develop snoring. They conclude that there is every reason to advise laser surgery for LAUP or UVPP and reduce the bulk to mimic appearance of OSMF!

Savage and Steward (2007) reviewed the literature for the number of options available to treat snoring in symptomatic patients. These options are wide ranging, they include over-the-counter snoring aids, oral appliances, and surgical options. Surgical options include uvulopalatopharyngoplasty, laser-assisted uvulopalatoplasty, radiofrequency thermal ablation therapy, injection snoreplasty, and palatal implants. However, while surgical options yield the best results, none of these methods are without their negative aspects. Surgical outcome is often surgeon-dependent. Other variables are relapses in snoring, peri-operative pain, recovery time, expense, and the ability to be performed in the office are also important considerations. The palatal implant system and radiofrequency thermal ablation have relatively promising outcomes, with little postoperative pain and comparatively self-limited complications. Furthermore, both procedures can be undertaken in office-based settings and thus cost efficient.

Sundaram *et al.* (2005) reviewed Cochrane database to assess the effects of any type of surgery for the treatment of the symptoms of obstructive sleep apnoea/ hypopnoea syndrome in adults. Their conclusion was that the review did not provide evidence to support the use of surgery in sleep apnoea/hypopnoea syndrome, as overall significant benefit had not been demonstrated.

In a prospective study of a cohort of 150 patients, Atef *et al.* (2005) set out to determine the number of sessions required to achieve both short and long term results in OSAS cases, comparing results following LAUP against bipolar radiofrequency volumetric tissue reduction of the palate (BRVTR). Their conclusion was that the BRVTR required a minimum of three sessions to achieve both short and long term results. In contrast, only one session was sufficient to achieve short term result when LAUP procedure was carried out. In order to achieve a long term result, two LAUP sessions were necessary. Increased number of sessions required with BRVTR is obviously due to lesser tissue damage.

In their case study, Olszewska *et al.* (2012) included patients who qualified to septoplasty, laserassisted uvulopalatoplasty (LAUP), uvulopalatopharyngoplasty (UPPP) and radiofrequency-induced thermotherapy of the tongue base (RITT). Outcome evaluation was performed on the basis of data received from follow-up laryngological examinations, selected parameters obtained from the Poly-Mesam test and follow-up questionnaires. Respiratory disturbance index improved by more than 50% after surgery. Loudness of snoring as well as blood saturation values improved. In the postoperative period there was short lived palatal deficiency in some cases. They concluded that surgical intervention in OSAS contributes to normalisation of sleep parameters, and majority of their patients experienced improvement in their symptoms.

And finally, in their quest to find the ultimate proof as to the effectiveness of LAUP to help the snorers, Larrosa *et al.* (2004) went as far as giving one group a ‘real’ operation and the other, simulated snore surgery followed by an oral placebo. No differences were observed in body weight, sleepiness, quality of life, subjective and objective intensity, frequency of snoring, and apnoea/hypopnea index between the groups before and 3 months after treatment. They concluded that the study showed lack of effectiveness of one-stage laser-assisted uvulopalatoplasty for snoring in non-apnoeic and mild obstructive sleep apnoea patients. This finding is in stark contrast with an almost universal finding that surgery does have a useful role to play in most cases of snoring and mild OSAS, albeit, its long term result do not seem to hold grounds of the high rate of initial success. This study also needs to be validated by further studies although in this day and age of internet literacy, freedom of information and patient expectations, there is very little room for any form of ‘sham surgery’!

Part B: Snoring and obstructive sleep apnoea

Y.V. Kamami, J. Krespi, V. Oswal, R. Simo,
A. Kacker and V. Kizhner

1. Introduction

Snoring has long been described as a socially disturbing experience. In 1836, Charles Dickens observed the association between obesity and daytime sleepiness in his description of Joe, the servant boy, in the *Pickwick Papers*: "His head was sunk upon his bosom; and perpetual snoring, with a partial choke occasionally, were the only audible indications of the great man's presence." In 1989, Hill added the symptoms of snoring and restless sleep.

Snoring and obstructive sleep apnoea syndrome (OSAS) has only become a health care issue in the last two decades. The condition was considered unimportant until the social problem of loud snoring and the serious effects of OSAS were identified and adequately investigated. Snoring and OSAS are a continuum of the same phenomenon, uncomplicated snoring being at one end and OSAS at the other, extreme end.

2. Incidence

It is estimated that in a 30- to 35-year-old population, 20% of males and 5% of females will snore. This incidence rises to 60% of males and 40% of females by the age of 60 years (Lugaresi *et al.*, 1980). The preponderance of male over female snorers cannot be explained, but legend has it that it is the need of primitive man to defend his woman even at night, by making terrifying noises to frighten away the beasts of prey (Boulware, 1974)! The *Guinness Book of Records* (McWhirter, 1986) states that the loudest snore was measured at 93 dBA. Snoring is more common in males, and its prevalence increases with age and body weight (Fairbanks, 1984).

3. Pathophysiology of snoring/obstructive sleep apnoea syndrome

Snoring is a loud and recurrent breath sound, with variable intensity and frequency, that occurs upon inspiration during sleep. It is correlated with age, sex, and body weight. OSAS is the most severe end of the sleep disturbance continuum. It is characterised by periodic apnoea and hypopnoea that produce asphyxia and arousal from sleep.

Snoring originates from vibration of the soft tissue structures in the pharynx, including the soft palate, uvula, tonsils, tonsillar pillars, tongue base, and the posterior and lateral walls of the pharynx. These vibrations occur because of airflow turbulence in the sleeper's pharynx, originating either in the nose, due to turbinate enlargement or septal deviation, or in the oropharynx. The turbulent airflow produces a flutter-valve effect in the collapsible pharyngeal tissues.

OSAS results from collapse of the pharyngeal walls in response to negative inspiratory pressure in the upper airway. Hypotonicity of the pharyngeal musculature allows upper airway collapse even at the most modest negative inspiratory pressures, leading to snoring or apnoea.

4. Diagnosis of snoring/obstructive sleep apnoea syndrome

A detailed survey that explores the snorer's medical condition, sleeping position, alcohol and sedative intake, and weight changes, is an important part of the history. Diagnosis of snoring is made primarily by history, much of which can be obtained from the patient's bed partner. The character and consistency of the snoring are examined to determine its severity and the possible presence of OSAS. Frequent episodes of breathing cessation followed by sudden and intensified snoring are strong indications of OSAS. Diagnosis of OSAS is confirmed by polysomnography. OSAS can be classified according to the apnoea-hypopnoea index (AHI) and oxygen desaturation.

The Epworth score is a very easy and effective method of assessing sleepiness. It consists of eight questions related to the chances of dozing off during specific activities and situations, *e.g.*, watching television, sitting, and reading. Each question is scored on a scale of 0, 1, 2, or 3. Zero indicates no dozing off and 3, always dozing off. The sum of the eight questions can give a maximum score of 24. A total score of less than 10 is considered not significant. A score of 10-12 is borderline, while a score of more than 12 is significant. The Epworth scale correlates extremely well with daytime somnolence, and provides an important yardstick for advising aggressive management.

5. Physical examination and assessment of snoring/obstructive sleep apnoea syndrome

The physical examination should include complete evaluation of the nose, nasopharynx, oral cavity, oropharynx, hypopharynx, and larynx. Flexible fibreoptic nasolaryngoscopy aids in this examination, as well as allowing the Müller manoeuvre to be performed. The Müller manoeuvre consists of inhaling against a closed mouth and nose in order to create maximal negative pressure in the upper airway (Fig. 1). This aids in the detection of any collapsing site in the pharynx.

6. Localising the site of snoring

Currently, the most widely practised method of detecting the level of snoring is by performing sleep nasendoscopy. However, not all clinicians agree that this is a good method. Acoustic frequency analysis (AFA) is being used with increasing frequency for evaluations and seems to be a promising method, but it is not yet readily available and has not been validated. Once OSAS has been excluded and the source of the snoring accurately located, its management can be planned. In the majority of snorers, the source will be at a palatal level. The aim of palatal surgery is to produce scarring and fibrosis of the soft palate so that it does not vibrate.

7. Non-surgical management

Surgical procedures to address snoring entail certain risks and discomfort. Therefore, it is prudent to attempt medical intervention or behavioral modification in appropriate circumstances.

Various non-surgical methods have been utilised to alleviate snoring and/or OSAS. These include behaviour modification, sleep positioning, and continuous positive airway pressure (CPAP). Sleep positioning may be sufficient in mild snoring. Nasal allergies should be treated when present. Elimination of tranquillisers, avoidance of alcohol prior to sleep, weight reduction using strict dietary measures, and daily exercise, are imperative. Exposure to upper airway irritants such as smoke and fumes must be eliminated.

Since both medical and behavioral management require prolonged follow-up and/or adherence to a restrictive life-style, not all patients are able to comply. Additionally, many patients do not respond to conservative treatment measures. Surgical management is generally preferred by young and middle-aged individuals.

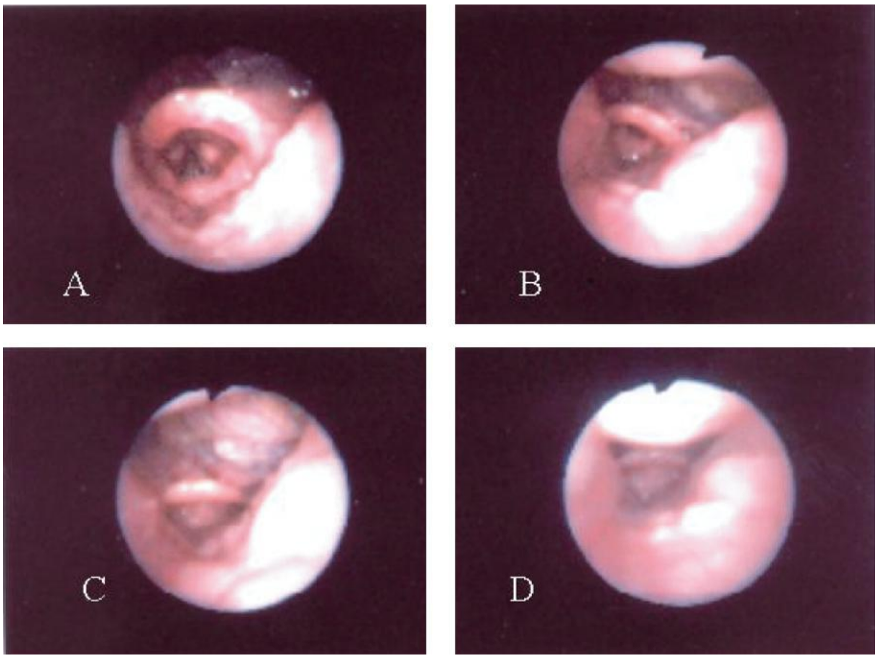

Fig. 1. The Müller manoeuvre consists of inhaling against a closed mouth and nose to create maximal negative pressure in the upper airway. This aids in the detection of any collapsing site in the pharynx.

8. Surgical management: historical perspective

Several different surgical approaches have been used in the management of snoring, the first of which was proposed by Ikematsu in Japan in 1952. In 1964, Ikematsu published his first large series of 152 patients with 82% relief from snoring (Fujita, 1994). In 1981, one of his followers, Fujita, introduced uvulopalatopharyngoplasty (UPPP) (Fujita *et al.*, 1981). This procedure was then modified and popularised by Simmons *et al.* (1983) in the USA. Since first described, there have been a number of papers reporting the results and complications of the various methods. The published literature describes success rates in excess of 70% in relieving the symptom of snoring.

9. Laser surgical management of snoring and obstructive sleep apnoea syndrome

There is now considerable experience with the use of lasers in the oropharynx. There is work advocating the advantages of using the laser over conventional techniques. The healing of wounds in the oral cavity and oropharynx has been widely studied. When laser and scalpel wounds of the oral mucosa were compared, there was less damage adjacent to the laser wound, reduced inflammatory reaction, and minimal contracture (Fisher *et al.*, 1983).

Non-laser surgical management of snoring and OSAS is outside the scope of this work. The surgical management of snoring and OSAS using lasers is covered in the following chapters.

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MCQ – 50. Laser-assisted surgery for snoring and obstructive sleep apnoea

Part A

1. The parameters for assessing success of surgical, non-surgical or both management strategies include
    a. Subjective assessment of snoring improvement by the partner
    b. Epworth sleepiness scale score
    c. Sequel such as globus sensation
    d. Severity and control of postoperative pain
    e. All of the above

2. According to the American Academy of Sleep Medicine (2010), the following protocol should be followed for (OSAS)
    a. The patient should be advised of the alternative management strategy such as nPAP or oral appliances and their effectiveness
    b. LAUP can be selectively advised as a treatment for mild cases of OSAS.
    c. In moderate OSAS, UPPP, as a sole procedure, or, with tonsillectomy, can normalize the AHI
    d. Tracheostomy is an effective option in all failed cases
    e. All of the above

3. Following LAUP,
    a. Weight *gain* can result in recurrence of symptoms
    b. Weight *loss* will result in recurrence of symptoms
    c. Weight *gain* will result in improvement of symptoms
    d. Weight *loss* will result in improvement of symptoms
    e. The surgical outcome following LAUP is not affected either by weight gain or weight loss

4. The advice to the patient for the management strategy for *non-apnoeic snoring* (or, primary snoring) is to undergo one of the following procedures
    a. UVPP
    b. LAUP
    c. Palatal stiffening
    d. cPAP
    e. There is no consensus for any of the above as gold standard

5. LAUP (laser assisted uvulopalatoplasty) versus RAUP (radio-frequency assisted uvulopalatoplasty:
    a. LAUP needs repeat treatments
    b. RAUP needs repeat treatments
    c. Pain following LAUP is more compared to that following RAUP
    d. Pain following RAUP is more compared to that following LAUP
    e. There is no conclusive evidence of one modality is better than the other

Part B

1. OSAS and snoring
    a. Are synonymous
    b. OSAS is a much more serious condition and requires active management

   c. OSAS is a continuum of long standing snoring
   d. OSAS is a separate entity and is remotely related to snoring
   e. Unlike snoring, OSAS is characterised by frequent episodes of breathing cessation followed by sudden and intensified snoring

2. The Müller manoeuvre
   a. Consists of inhaling against a closed mouth and nose in order to create maximal negative pressure in the upper airway
   b. Is useful for the diagnosis of OSAS
   c. Is the reverse of the Valsalva manoeuvre
   d. Is undertaken to detect any collapse of the pharyngeal structures
   e. All of the above

3. Sleep nasoendoscopy is undertaken
   a. To diagnose OSAS
   b. To assist in non-surgical management of snoring (*e.g.* anti-allergic treatment)
   c. To localise the site of obstruction to breathing
   d. To localise the site of snoring
   e. All of the above

4. Any surgical management of snoring should be complimented by
   a. Psychological counselling
   b. Dietician counselling
   c. Behavioural counselling
   d. Sleep positioning
   e. All of the above

Chapter 51

Laser-assisted uvulopalatoplasty

J. Krespi, V. Kizhner and A. Kacker

1. Laser-assisted surgery for snoring and obstructive sleep apnoea syndrome

The operation of LAUP was developed as an alternative to traditional UPPP for the treatment of snoring due to palatal flutter. Various methods of performing the procedure have been described. Kamami (1994) first described the procedure in 1990 and coined the name laser-assisted palatoplasty under local anaesthesia, using a CO_2 laser delivered via a specially designed handpiece. The subsequent fibrosis combined with the decrease in bulk of the soft palate has been shown to be effective in reducing snoring. LAUP has relatively few long-term complications when compared to the more extensive UPPP. Krespi *et al.* (1994) described a similar technique. They advocate surgery, undertaken in sequential sessions, to reach an adequate result with minimal morbidity such as nasal regurgitation or voice change.

Early in 1994, Ellis and co-workers described a different technique, based on work with colleagues from the Department of Acoustic Engineering at Cambridge University, in the UK. This work suggested that snoring caused by palatal flutter could be controlled by stiffening the soft palate. The handheld Nd:YAG laser was used to remove a longitudinal strip of mucosa from the soft palate (Fig. 1A-D).

LAUP is a technique developed by Kamami in France in the late 1980s. It was introduced into the USA as a treatment for snoring without apnoea in 1992. The procedure is designed to correct airway obstruction and soft tissue vibration at the level of the soft palate, by reducing and stiffening the tissues in the velum and uvula.

2. Contraindications

There are relatively few absolute contraindications to LAUP in an office setting, but these include: significant sleep apnoea (AHI greater than 30), uncontrolled hypertension, trismus, cleft palate, pre-existing velopharyngeal insufficiency, uncooperative patients, and an anatomical source of snoring other than the oropharynx, such as gross nasal or maxillofacial problems.

Caution should be exercised in patients who use their voice professionally or who play wind instruments. Linguistic constraints for certain languages that use the soft palate or the uvula extensively, such as Arabic, Russian, Hebrew, and Farsi, may also be a consideration. Patients with allergies to local anaesthetics and a hyperactive gag reflex should be treated under general anaesthesia. In OSAS, LAUP may be indicated if the syndrome is still mild. In severe OSAS, it may help induce tolerance and reduction of pressure in CPAP management.

3. Choice of laser

Almost any laser can be used for LAUP. The main considerations are capital outlay, availability of a particular laser within a hospital or clinic setting,

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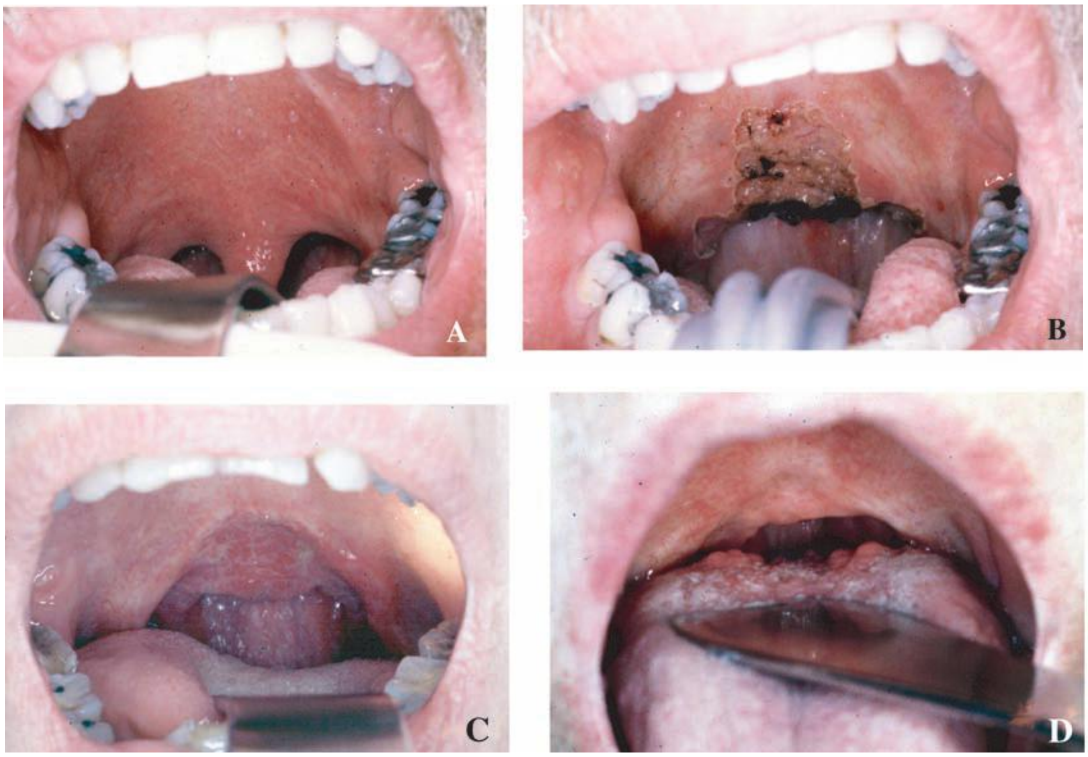

Fig. 1. Removal of uvula and shortening of palate by fibrosis, with Nd:YAG laser. (Courtesy M. Remacle)

feasibility of ambulatory or day case surgery, delivery of energy to the operation site, etc.

The Nd:YAG, diode, KTP/532, Ho:YAG and argon lasers are fibre-transmissible. Thus, they provide useful tactile feedback. However, the contact of the tip with the palate may provoke a gag reflex. The diode and KTP/532 lasers are compact portable machines, suitable for office procedures in diverse locations. The diode machine is marketed at a much lower price. The Nd:YAG should only be used in the contact mode, since the wavelength scatters widely within the tissue in the free-beam mode. The Ho:YAG is a pulse laser with the splattering of the tissues requiring a dedicated, combined, suction-fibre system. Its high energy and latent period before the first pulse energy is emitted makes it unsuitable for office procedures. Although not fibre transmissible, the CO_2 laser is easier to use with precise and rapid debulking and ablation of the tissue with a Surgitouch flashscanner. The CO_2 laser seals off small blood vessels, offers a good intraoperative visibility, and has an insignificant rate of postoperative bleeding and haematoma. Thus, LAUP with the CO_2 laser is most suited for patients on anticoagulation therapy. Some authors prefer conventional or electrosurgery (ES) to laser surgery.

4. Surgical procedures with laser-assisted uvulopalatoplasty

The overall goal is to reduce the length of the palate and to reshape the uvula. LAUP is performed in an upright sitting position in an otolaryngology examination chair. A topical anaesthetic such as benzocaine 20% is sprayed into the posterior oral cavity over the soft palate, tonsils, and uvula. After three minutes, a 1.0 ml mixture of 2% lidocaine with 1:100,000 epinephrine and 0.5 ml of 0.5% bupivicaine is injected at the junction of the soft palate and the uvula bilaterally and into the base of the uvula. If laser ablation of the tonsils and the tonsillar pillars is to be performed, an injection is also given into the superior junction of the anterior and posterior pillars bilaterally.

The laser procedure is started after ten minutes, in order to allow for adequate anaesthetic effect and vasoconstriction. A CO_2 laser is preferred due to its wide availability and ease of use. Even though the CO_2 laser is not the best coagulating laser available, it has adequate coagulation for the size of the vessels encountered with this procedure. The following description outlines LAUP performance with the CO_2 laser.

The patient and staff are equipped with protective

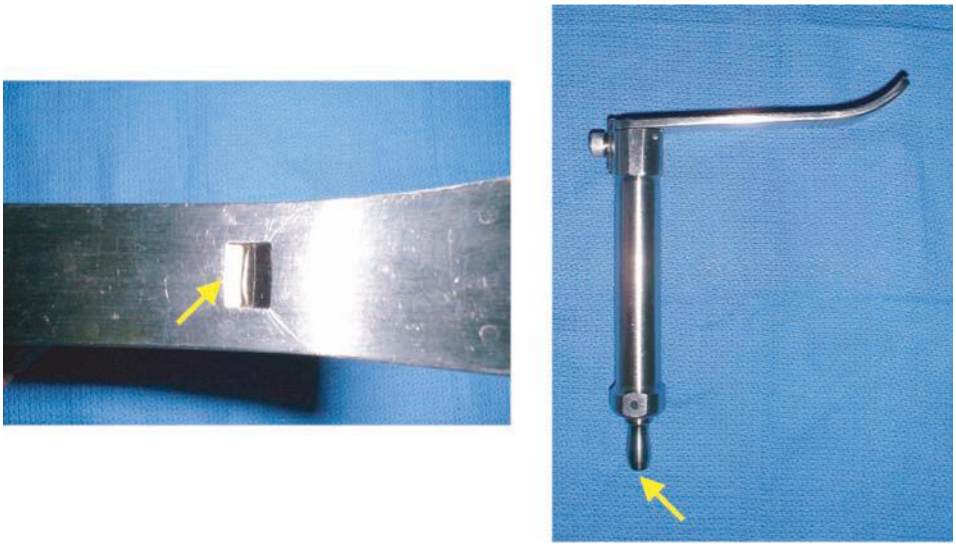

Fig. 2. The tongue is retracted inferiorly with an ebonised tongue depressor, which has an integrated smoke evacuation channel (arrow).

goggles, and laser safety rules are followed. The power is set at 18-20 W in the continuous mode. The tongue is retracted inferiorly with an ebonized tongue depressor, which has an integrated smoke evacuation channel (Fig. 2). The patient is asked to inhale, and the laser is activated during slow exhalation in order to avoid inhalation of the plume.

Shortening and thinning of the uvula are carried out with the regular handpiece in the defocused mode or with a Swiftlase flashscanner. The uvula is reduced to 70-80% of its original size by coring it in a cephalic direction. Through and through, full thickness, vertical trenches measuring 1.0-1.5 cm are fashioned on the free edge of the soft palate at either side of the uvula (Fig. 3A-D). These trenches are created using a focused beam and a special handpiece with a backstop (Fig. 4). Care must be taken not to burn the mucosal covering of the soft palate and the uvula excessively. The uvula is shortened by ablating the muscle from within, creating a ‘fish-mouth’ appearance, while preserving the mucosa of the base of the uvula on the nasal and oral surfaces (Fig. 5). Light bleeding can occur during surgery in 3% of patients. This is easily controlled by applying silver nitrate.

5. Postoperative instructions

Patients can resume regular activities immediately following surgery. A soft, bland diet, avoiding citrus products, is recommended. Aggressive hydration, humidification, and steam inhalation are emphasised. Mucous membrane dehydration is thought to be an important source of postoperative pain. Viscous xylocaine is used to relieve pain every few hours, as needed. Gargling with diluted hydrogen peroxide or nonalcoholic mouthwashes is recommended. The need for analgesics varies according to each patient’s tolerance level. Various analgesics, such as acetaminophen, acetaminophen with codeine, or oxycodone hydrochloride, can be used. Prophylactic antibiotics are prescribed in all patients. However, steroids are not indicated in this group of patients.

Typically, LAUP requires three to four treatments, a minimum of six to eight weeks apart. The time elapsing between the procedures allows proper healing of the soft palate mucosa. The endpoint of LAUP is when significant reduction or elimination of snoring has occurred. Confirmation is obtained by patient or partner history and/or by the inability of the patient to perform voluntary snoring.

6. Patient risk and benefit

Krespi and co-workers (1998) reviewed 280 patients who underwent LAUP in the office, with a follow-up of three months to two years. They reported an 84% elimination of snoring, and an additional 7% *reduction* of snoring. Carenfelt (1991) reported an 85% total or near total elimination of snoring during a short-term follow-up (duration not specified) of 60 patients. In a review of 741 patients, with a maximal

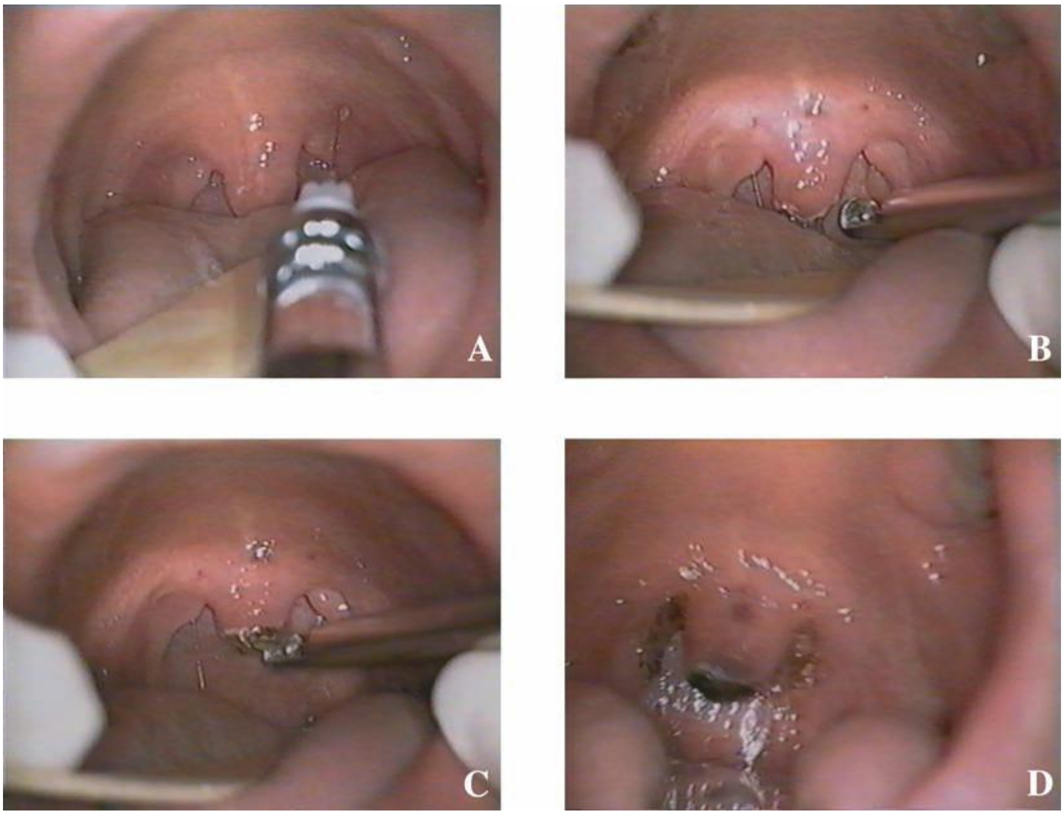

Fig. 3. LAUP (Kamami) showing shortening of uvula and palate by creating trenches by the side of the uvula.

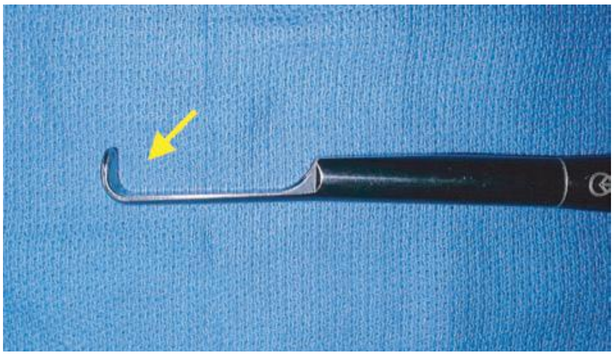

Fig. 4. The trenches are created using a focused beam and a special hand-piece with a backstop (arrow).

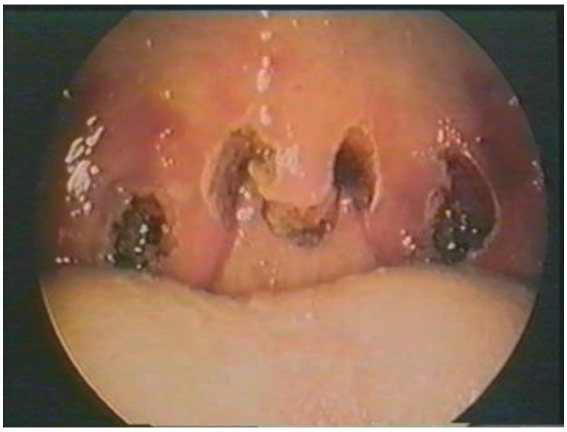

Fig. 5. The uvula is shortened by ablating the muscle from within, creating a "fish-mouth" appearance, while preserving the mucosa of the base of the uvula on the nasal and oral surfaces.

follow-up of five years, Kamami (1994) reported a 69.8% cure or significant reduction of snoring. Ellis (1994) published the results of laser palatoplasty in 16 patients with a three-to-six-month follow-up. The surgical technique described by Ellis was slightly different, in that only a central longitudinal strip of mucosa was removed from the surface of the soft palate. This resulted in an 85% elimination or significant reduction of snoring.

Prolonged follow-up revealed more modest success with this operation. Walker *et al*. (1999) and Mickelson and Abuja (1999) presented long-term results of LAUP treatment for snoring. Eight years after treatment, Kamami (1994) found that 37% of patients who were initially cured had a recurrence of their snoring. This was mainly related to a nasal obstruction (septal deviation, turbinate hypertrophy), or to weight gain. In most of the cases, appropriate treatment of the nasal obstruction cured or improved the symptom of snoring.

Complications with LAUP are rare. Intraoperative bleeding can occur in 3% of patients. This is usually from the apex of the palate trench incision and is stopped by the application of silver nitrate. There was only one episode of delayed bleeding in a series of 2254 LAUP procedures carried out by one of the present authors (VK). No patients required hospital admission or a transfusion.

Moderate to severe pain is the major side-effect of the procedure. Pain intensity reaches its peak four to five days postoperatively, with complete relief of symptoms after two weeks. Pain is usually well controlled with hydration, anaesthetic gel, and oral analgesics. Most patients report some degree of weight loss, typically less than ten pounds over the course of treatment. Healing occurs by the formation of eschar within three to five days following the procedure. Complete mucosal healing takes place following the sloughing of eschar after about 12 days.

Krespi (1998) reported two vasovagal episodes following the injection of local anaesthetic in a review of 280 patients.

Velopharyngeal insufficiency, either temporary or permanent, has not been reported, probably due to the graded surgical approach. Nasopharyngeal stenosis has not been encountered because, by using the special handpiece with its backstop to make the palatal incisions, the nasopharyngeal mucosa is protected from injury. Approximately 40% of patients may complain of a 'scratchy' or 'dry mucous' sensation in the throat. This is usually self-limited and resolves within two months.

7. Discussion

LAUP is an effective method for treating patients with loud, habitual snoring, upper airway resistance syndrome, and mild OSAS. It has several advantages compared to classical UPPP, including reduced cost, decreased operative morbidity, diminished postoperative pain, and abbreviated convalescence period, as well as the avoidance of general anaesthesia.

LAUP as an office procedure, performed under local anaesthesia, has proved to be a safe and effective method of alleviating bothersome snoring. Surgery is undertaken in stages to allow 'titration' of tissue removal with a minimal risk of overcorrection. Patient selection requires careful review of the medical history and a thorough physical evaluation. The nose, tongue base, and hypopharynx should be ruled out as the primary site of airway obstruction. Polysomnography is indicated in those patients at risk for OSAS. When performed in properly selected candidates, LAUP can result in an excellent clinical outcome and patient satisfaction.

8. An illustrative case

8.1. History

A 50-year-old man presented for snoring. His wife had refused to sleep in the same bedroom for the previous three years due to the intensity of his snoring. She denied episodes of breathing cessation. The patient did not smoke or consume alcohol or sedatives.

8.2. Examination

Examination showed mild obesity, with the patient being five feet six inches tall and weighing 179 pounds (calculated Body Mass Index: 27.4). Mild hypertension was present. Nasal examination did not demonstrate significant septal deviation or turbinate enlargement. Intraoral evaluation revealed a flat-appearing palate, an elongated thick uvula, and thick posterior pharyngeal folds. Fibreoptic nasopharyngoscopy showed no enlargement of the lingual tonsils and absence of hypopharyngeal collapse on the Müller manoeuvre.

8.3. Diagnosis

Snoring due to mild obesity, thickened uvula, and redundant thick lateral pharyngeal folds.

8.4. Anaesthesia

Topical benzocaine 20% spray applied to the posterior oral cavity, followed by injection of a mixture of 1.0 ml 2% lidocaine with 1:100,000 epinephrine and 0.5 ml 0.5% bupivicaine into the soft palate.

8.5. Procedure

Two LAUP procedures at ten-week intervals were performed using the CO_2 laser at 18 W in the continuous mode. Full-thickness vertical trenches measuring 1.0 cm were made on either side of the uvula with a focused beam. The size of the uvula was reduced by 70-80% with a Surgitouch flash-scanner.

8.6. Postoperative results

The patient's snoring is now nearly inaudible and he is unable to perform a voluntary snort. The patient and his wife are again able to share the same bed. The patient reports better quality of sleep, ability to dream, and reduced morning fatigue.

9. Modifications in standard LAUP

As the experience gathers, several workers modify the standard technique for LAUP. Kamami, the pioneer of the technique presented his modification as below, at the Poster session held during the AAO meeting, San Diego, in 2009 (poster 435).

The procedure consists of resection of uvula and one median palatal trench, thus leaving a very small new uvula. The procedure is performed with a CO_2 laser using Surgitouch with 40 watts setting. The concept of a single trench is 'alluring and intriguing'. The end result of palatal expansion seems as logical as traditional LAUP. The benefits as reported include: shorter operation time (5-15mn), pain reduction in intensity and duration due to less tissue resection and less residual raw surface, less snoring intensity, reduction in dry mouth sensation, reduction in rebleeding and quicker return to daily activity. Kamami reported treating 1625 patients with the new technique. This technique yet awaits to be popularised and put to objective studies.

10. Somnoplasty using radiofrequency

Recently, radiofrequency (RF) has been used to undertake somnoplasty, etc. The equipment consists of an RF generator with custom-made needle electrodes and delivery device. RF is delivered at 465 kHz, with energy parameters such as power, temperature control, resistance and total energy, controlled by a computerised energy algorithm.

The target temperature of 80°C, attained with a low power setting of 2-10 W, with an exposure duration of 60-180 seconds, results in sufficient shrinkage of the soft palate, during the 60-170 seconds burst of treatment. In common with the use of any hi-tech device, RF technology requires a good level of skill and training. When adequately used, RF technology offers some distinct advantages: the procedure is undertaken under local anaesthesia, and can be completed in less than 30 minutes. Postoperative pain is of relatively short duration, lasting for 48 hours, and can easily be controlled with acetaminophen. The oedema peaks at between 24 and 48 hours, but with no clinical airway compromise. As with the CO_2 laser, no stenosis or nasal regurgitation is experienced following RF. Thus, electrosurgery is a good cutting instrument, is simple to use, inexpensive, and has adequate intraoperative haemostasis.

However, there are some disadvantages of RF versus the laser: a full view of the operating site is somewhat obstructed due to the presence of needle electrodes. Worsening of the respiratory disturbance index (RDI) and oxygen saturation level (SO_2) was seen by Powel *et al.* (1998), who also noted that, in subjects with substantial breathing and sleep disorders, postoperative oedema with the risk of upper airway compromise could give rise to concern. Both the CO_2 laser and RF are expensive tools and need specific training for their safe operation. RF users need to control safe and optimal shrinkage of the delicate tissues of the palate in order to avoid palatal necrosis and perforation. RF may be more expensive if the treatment is spread over several sessions, since frequent, single-use, expensive needle electrodes would be necessary. As the follow-up of this new technique is still very short, and the technique modalities have not yet been clearly defined, it is difficult to know the frequency of sessions necessary to obtain long-term results.

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MCQ – 51. Laser-assisted uvulopalatoplasty

1. CO_2 laser is most suitable for LAUP in patients
    a. Who are on anticoagulants
    b. Who are suffering from hypertension
    c. Who have got trismus due to oral submucous fibrosis
    d. Who are professional voice users
    e. All of the above

2. CO_2 laser is *unsuitable* for LAUP because
    a. It is not fibre transmissible
    b. It is not a good coagulator
    c. Its beam is collimated and thus cannot be defocused for haemostasis
    d. It is invisible and therefore requires an aiming He-Ne beam which may not exactly superimpose it and result in non-target strikes
    e. None of the above

3. For CO_2 laser LAUP, pre-operative counselling should consist of:
    a. Staged procedure if electively planned
    b. Likelihood of postoperative bleeding requiring admission
    c. Nasal regurgitation, change of voice
    d. Postoperative pain peaking at forth to fifth day and resolution in two weeks
    e. In three out of ten patients, the initial short term improvement is not be maintained after a variable period of time and further procedure may be necessary

4. Which of the following statements are correct?
    a. Lack of optical fibre transmissibility for the CO_2 laser is an advantage since it provides an unobstructed view of the target
    b. In non-contact mode, the Nd:YAG laser exhibits much *less* scattering and as such, Nd:YAG laser should be used in non-contact mode for LAUP
    c. KTP laser is fibre-transmissible and provides a useful tactile feedback. However, it may provoke a gag reflex in some patients
    d. Diode laser is a low cost portable laser and provides a good alternative for LAUP
    e. Radiofrequency application results in more oedema compared to the laser application in LAUP

5. Uvula
    a. Its complete removal results in nasal regurgitation
    b. At least 50% of its length should be left behind
    c. At least 20-30% of its length should be left behind
    d. After surgery, its posterior surface should be longer than the anterior surface to ensure adequate nasopharyngeal closure
    e. If both the anterior and the posterior surfaces are not equally removed the snoring is not completely cured

6. During the postoperative course, the salient feature which requires an active management is
    a. Difficulty in swallowing
    b. Nasal regurgitation
    c. Bleeding
    d. Pain
    e. Infection

7. Somnoplasty with radiofrequency
    a. Results in less pain
    b. Results in more oedema
    c. Is more expensive due to single use needle electrodes
    d. Requires more skill than the laser
    e. Gives equitable results

Chapter 52

Palatal stiffening via transoral, retrograde interstitial laser coagulation

J. Krespi and V. Kizhner

1. Introduction

Snoring affects as high as 20% of the population and may impact breathing during sleep. Surgical and non-surgical treatment options for snoring have soared in the past years. With the advent of minimally invasive office procedures, laser palatoplasty, radiofrequency (RF) volumetric reduction and the pillar procedure are being increasingly advocated. The use of oral appliances has also increased. The patient expectations for an elective snoring therapy, particularly in the absence of OSA, are understandably very high. Patient satisfaction is greatest when an effective, low cost office procedure is available with minimal post-surgical down time (Krespi and Kacker, 2002).

2. Uvulo-palato-pharyngoplasty

Uvulo-palato-pharyngoplasty (UPPP) is usually performed under general anaesthesia. It is generally successful in eliminating snoring. However, it is associated with significant morbidity since there is considerable post-operative pain. Some workers believe that the pain from UPPP, performed in the absence of obstructive sleep apnoea, is ‘overkill’ and does not warrant its use for cases of simple snoring (Main *et al*., 2009).

3. Laser-assisted uvulo-palatoplasty (LAUP) and radio-frequency procedure (RF)

Laser-assisted uvulo-palatoplasty (LAUP) and radiofrequency procedure (RF) can be performed under local anaesthesia in the office, but both are also associated with significant postoperative discomfort. Both Laser or RF are used in ablative mode to reduce palatal bulk. The intra-palatal scarring results in stiffening of the palate. While in general both procedures produce symptomatic relief, they have some inherent drawbacks:

- The conventional palatal procedure is associated with significant discomfort and swelling which affects oral intake for a few days following the procedure;
- The surgical outcome depends on surgical skill, since standardisation of laser parameters cannot solely influence the outcome. Repeat procedures may be necessary, adding to the overall costs;
- Variable uvular management also influences the results;
- It is not always possible to accurately control the energy parameters;
- Although previous studies showed good short-term results from the use of radio frequency, recent studies failed to show long-term benefits (Stuck, 2009; Bäck *et* al., 2009);
- Complications such as erosion and ulceration may occur;
- Revenue costs of disposables are significant.

Lasers are a commonplace in ENT office practice

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with a wide range of applications. Compared to monopolar cautery, the laser creates less tissue necrosis and less thermal damage (Krespi and Kacker, 2002). Histopathological comparison between RF and diode laser in the pig`s nasal mucosa showed necrosis and ulceration, fibrin deposition in the mucosa, necrotizing sialometaplasia, as well as proliferation of the granulation tissue. As total energy delivered in each modality is hard to judge, the comparisons are not valid (Zboráyová, 2009).

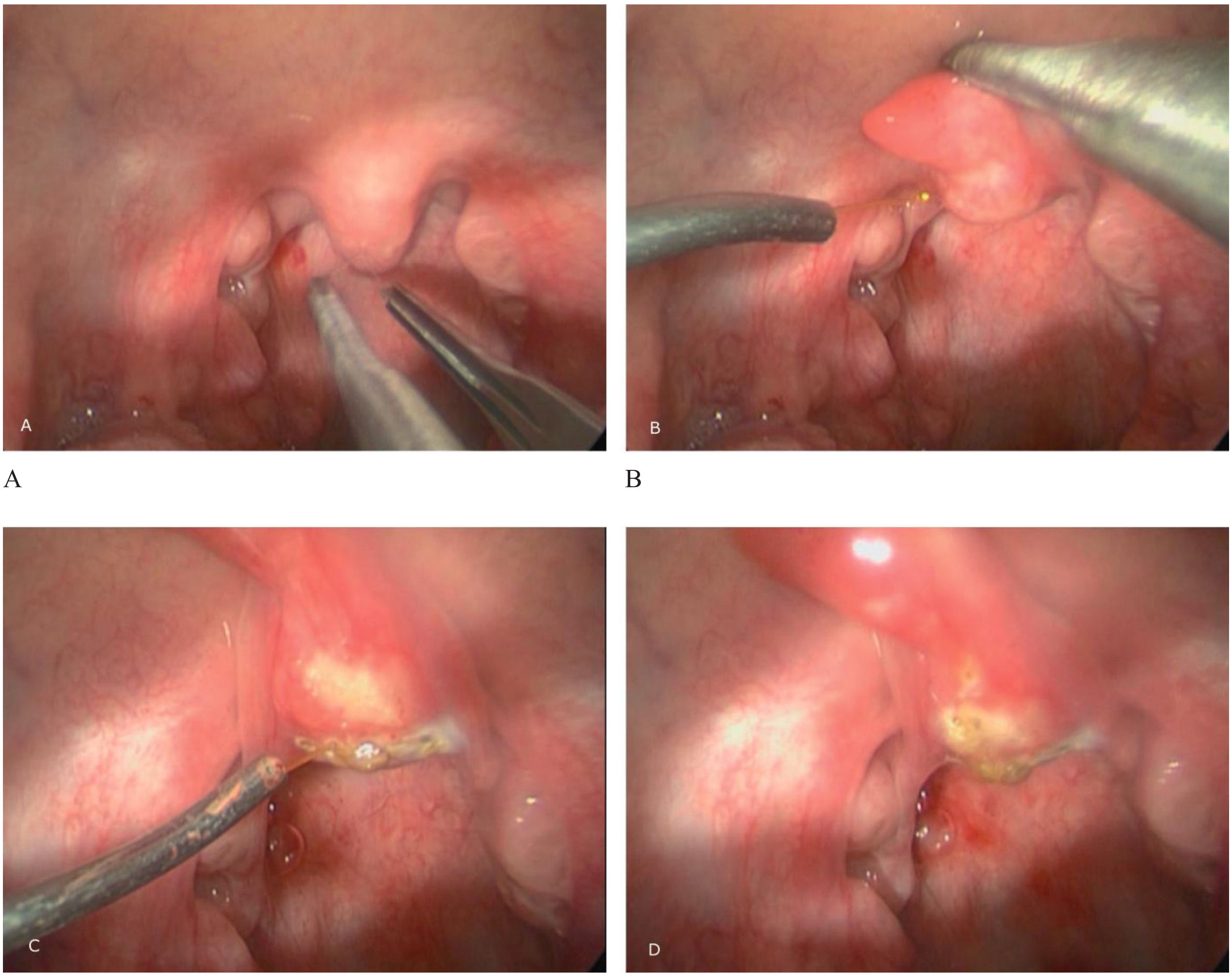
4. Trans-oral retrograde laser procedure

The authors describe a new minimally invasive and yet effective method for the treatment of snoring. Palatal stiffening is addressed in a retrograde fashion. The trans-oral retrograde approach avoids injury to the *oral* surface of the palate by targeting the palatal muscle on its nasal surface. There is much less postoperative discomfort during swallowing.

5. The 980 nm diode laser

The 980 nm near-infra-red (NIR) diode laser (A.R.C. laser, Nürnberg, Germany) is ideally suited for office based procedure for the management of snoring (without associated OSA). It is a small compact and economical unit, free from maintenance needs. It is cost effective. It is fibre transmissible and the energy can be applied in non-contact mode or trans-palatal, in to the substance of the palate. It has a good haemostatic property.

A flexible fibre is connected to the unit. The other end is attached to a hand-piece with curved needle



A

B

C

D

Fig. 1. Trans-oral retrograde laser procedure A: The uvula is flipped upwards. B: The laser is about to be introduced retrogradely in the flipped uvula. C: Retrograde interstitial laser ablation on the pharyngeal side. D: The end result.

tip. Energy is set at seven to eight watts. The needle tip is used in contact mode or interstitially in to the palatal muscle.

An ergonomically designed hand-piece ensures delivery of precise energy. The trans-oral retrograde approach is remarkably free from complications, most probably due to lack of contamination of the wound from oral feeds (Kreisler *et al.*, 2003).

6. Method

Patient selection is based on the results of Polysomnography (PSG). Patients with a minimal sleep apnoea score (RDI < 7) with symptoms of snoring are recruited. A full informed consent is obtained. A 980 nm NIR laser with 300 micron fibre is used. The fibre is coupled to a surgical hand piece and curved needle tip is used to deliver the energy. Laser power is set at seven to eight watts in continuous mode.

The tip of the uvula is grasped gently with forceps and flipped anteriorly. The laser fibre is inserted penetrating the nasal surface of palatal mucosa around the base of the uvula and advanced further anteriorly into the soft palate muscles. At least three passes are made (one centrally and two laterally) for about ten seconds. The laser fibre was advanced in a retrograde fashion about two to three cm from the base of the uvula in the midline and two additional lateral passes are made (Fig. 1, ABCD). The total energy delivered in to the palatal musculature is no more than 1000 joules.

7. Results

As anticipated, most patients reported significant improvement. However, a small number did not respond to the treatment. Snoring is multifactorial, and it is likely that in some patients trans-oral application of laser is not sufficient. Other causes may be contributory and further assessment is required such as sleep posture, life style and so on. Significant improvement is found in those who sleep on their side and who have clear and open nasal passages.

The majority of patients experienced only a mild pain, but some reported pain of moderate severity. The results are sustained over a year's follow up with a high overall patient satisfaction. The surgical time was short and local anaesthesia in the office setting ensures a quick recovery.

The fibre is cleavable and thus can be used on several patient, adding to the cost effectiveness of the procedure.

8. Conclusion

The validity of this approach cannot yet be ascertained with any certainty since both the cohort and a follow-up period is small. Nevertheless a postero-anterior trans-oral interstitial ablation of the central area of the soft palate, performed in the office settings, offers an option for most of the criteria for an ideal treatment for snoring (without associated OSA).

The technique is office based, cost effective with minimum capital outlay and revenue costs since the fibre is reusable. Most patients reported benefit, with low postoperative morbidity. Unlike trans-oral procedure, the oral intake is unaffected. The 980 nm diode wavelength has an excellent tissue absorption for the palatal tissue, without significant bleeding.

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MCQ – 52. Palatal stiffening via transoral, retrograde interstitial laser coagulation

1. The diode laser used for palatal stiffening emits at
    a. 810 nm
    b. 980 nm
    c. 830 nm
    d. 670 nm
    e. 867 nm

2. Trans-oral retrograde laser procedure consists of
    a. Passing the optical fibre through a curved cannula so that the laser beam strikes the posterior surface of the palate
    b. Flipping the palate anteriorly so that the posterior surface is exposed in the oral cavity
    c. Reflecting the beam in a mirror so that it strikes the posterior surface of the palate
    d. Puncturing the oral surface of the palate with a fibre and position it in the vicinity of the posterior surface of the palate.

3. Interstitial retrograde ablation of the palate has the following advantages:
    a. Avoiding raw area in the oral cavity
    b. Fluid and food intake is relatively unaffected
    c. Less pain when compared to the conventional uvulopalatoplasty
    d. Office based procedure
    e. All of the above

4. For retrograde method, the respiratory disturbance index (RDI) should ideally be
    a. Less than 7
    b. Less than 12
    c. Between 10 and 20
    d. Estimated by Polysomnography
    e. Contraindicated in cases of obstructive sleep apnoea syndrome

5. Palatal stiffening can be achieved by
    a. Diode laser
    b. RF
    c. Implantable palatal Polyethylene Terephthalate (PET) sutures
    d. Alcohol injection
    e. All of the above

Chapter 53

Laser-assisted septoplasty

V. Kizhner, J. Krespi and A. Kacker

1. Introduction

Nasal obstruction due to septal deviation and/or enlarged turbinates is one of the most common problems encountered by otolaryngologists. Obstruction due to enlarged turbinate can be managed using multiple surgical modalities such as cold instruments, diathermy and lasers. The role of laser in the management of enlarged turbinate is described in Chapter 22.

Unlike turbinate surgery, where multiple modalities are used, the technique for nasal septal surgery remained unchanged since its inception. The surgical procedure is carried out with cold instruments. It consists of elevation of mucoperichondrium flap and excision or recontouring of the obstructing bone and cartilage.

In the past couple of decades, laser technology has made inroads to correct the nasal obstruction due to deviated nasal septum. An isolated bony and cartilaginous spur, along with the overlying mucosa, can be surgically removed with the laser. It is also possible to tackle the deviated cartilagenous septum using *non-surgical* laser technique. This chapter covers laser management of nasal obstruction due to an isolated unilateral spur. Chapter 62 covers laser cartilage reshaping of deviated cartilaginous septum.

2. Which laser?

In most ENT departments, the CO_2 laser is the laser of choice for most needs to the extent that it is considered a workhorse laser. However, the CO_2 laser wavelength does not transmit via the optical fibre. It can therefore be used only for anterior spur and enlarged anterior end of inferior turbinate. Various accessories are available which will take the CO_2 laser deeper in to the nostrils, but these tend to be somewhat bulky.

Hollow waveguides, such as the Omniguide or the recently introduced FibreLase, do transmit the CO_2 laser beam. These waveguides are marketed for single use and are thus cost prohibitive. See Chapter 59 for further reading.

Diode laser (emitting at 810-1024 nm wavelength, commonly used ones emit at 980 nm) is fibre-transmissible, and is considered to be the ideal laser for rhinology. Anterior as well as posterior spurs are easily accessible for treatment with diode fibre without collateral non-target damage.

3. Selection of patients

Patients are selected with the same criteria as for standard septal operation following a compatible history with a matching exam. The NOSE criteria (Nasal Obstruction Septoplasty Effectiveness) are particularly useful for monitoring surgical outcome (Stewart *et al.*, 2004).

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4. Local anaesthetic

Surgery is performed under local anaesthesia under endoscopic control using the 0° nasal endoscope. The topical application of 0.05% oxymetazolin with 4% lidocaine is used for topical anaesthesia as well as for vasoconstriction.

5. Procedure using CO_2 laser

Patients diagnosed with nasal obstruction due to anterior nasoseptal deformities, based on anterior-rhinoscopy and acoustic rhinometry, are selected for laser-assisted septoplasty using a CO_2 laser in the superpulse mode to prevent charring.

The Lumenis laser with the Surgitouch scanning device is used with a modified Kamami nasal hand piece (Fig. 1) attached to the standard oral hand piece. The laser is set up at 12-15 W in the Superpulse continuous mode. Transmucoperichondrial resection of the spur is then performed. The Superpulse mode with the Surgitouch scanning device allows for char-free resection of the spur, and also reduces tissue damage, leading to decreased postoperative oedema and crusting.

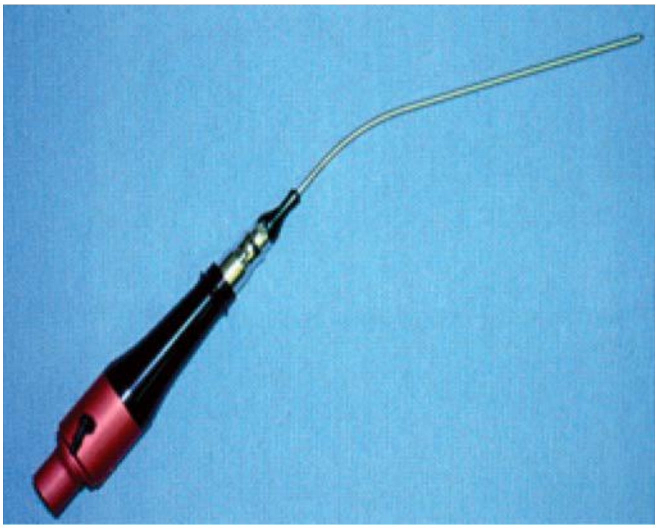

Fig. 1. Dedicated hand piece for CO_2 laser

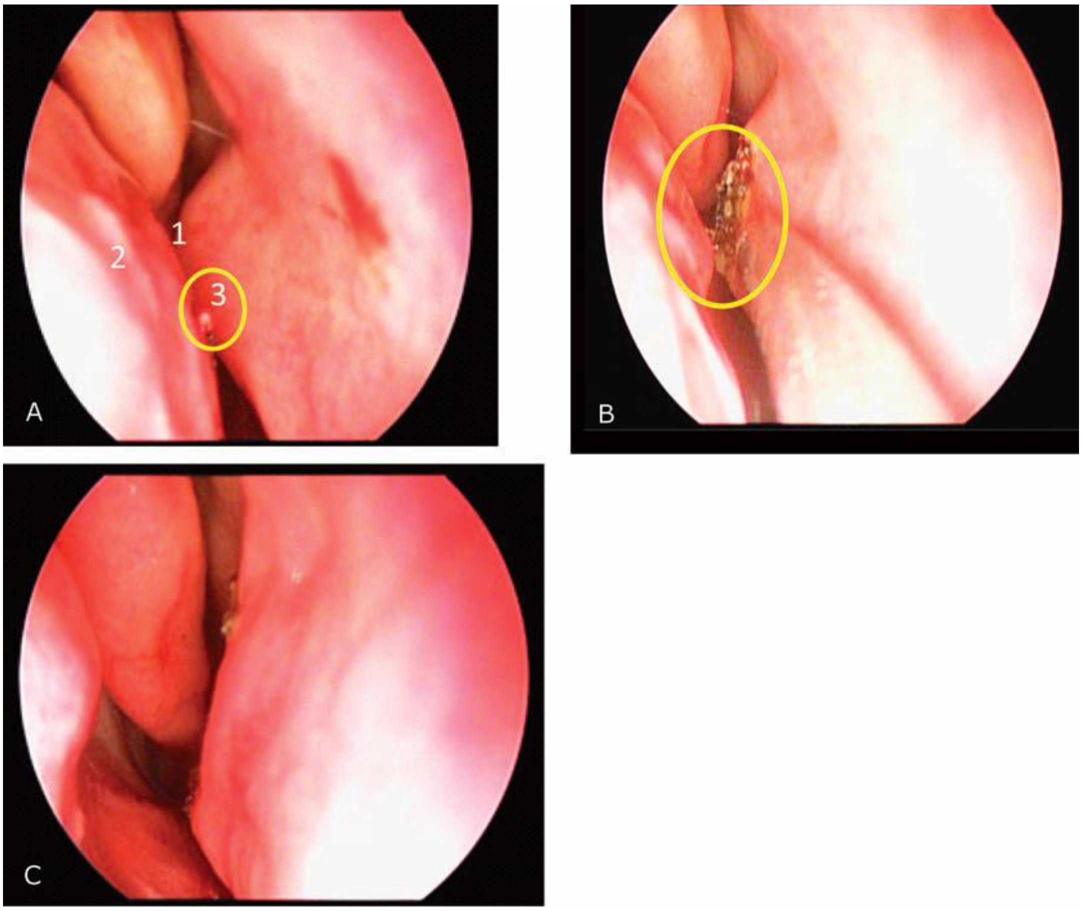

Fig. 2. A: Preoperative: 1: Septum with a spur; 2: Inferior turbinate; 3: tip of the diode laser fibre, circled. B: Intraoperative: vaporisation of spur. C: Postoperative result

6. Procedure using diode laser

A diode laser with a choice of 810-1024 nm wavelength (usually 980nm) is used with a power setting of 5-6 W in the continuous mode. This wavelength of the diode device has a high absorption rate for haemoglobin achieving good haemostasis of intact blood vessels. Haemostatic effect is not achieved if the operating area is covered with blood, since most of the energy will be absorbed by extravasated blood.

The laser is connected to a 300 µ flexible *bare* fibre. The other end is inserted in to a specially designed hand piece. Unlike the CO_2 laser, the diode laser has to be activated in contact mode for effective tissue ablation. The fibre is introduced in to an accommodating hand piece and the tip is charred. Under direct vision with a 0 degree nasal endoscope, the spur and the underlying cartilage are resected until a desirable airway is achieved (Fig. 2A-C). Any accumulated char is removed and minor bleeding is controlled by application of a wet cottonoid soaked in 0.05% oxymetazoline to prevent postoperative crusting or adhesion.

7. Reshaping deviated septum

For fuller description, see Chapter 62. Briefly, laser radiation is used to heat the cartilage and the mucosa, without devitalising the tissues (Ovchinnikov *et al*., 2002). A modified nasal speculum is inserted to mechanically reshape the cartilage to achieve the patency of the nostril. Optoacoustic sensors measure the internal stress to monitor the reshaping process.

Holmium:YAG laser (wavelength: 2.09 µm; pulse duration: 500 microseconds; pulse energy: 0.2-0.4 J; and pulse repetition rate: 5 Hz) is used to heat the cartilage. The energy is delivered with a side-firing fibre. A feedback-controlled monitoring system terminates laser heating when adequate stress relaxation has occurred.

A similar approach with a different laser system using Erbium doped glass fibre laser emitting at 1.56 µm and power setting at 4.1 W is also described (Bourolias *et al*., 2008).

8. Patient risk and benefit

Cold instrument septal surgery has a 70% long-term success rate as reported in a number of large series. (Samad *et al*., 1992; Low and Willatt, 1992). However, complications are not uncommon and include nasal bleeding, septal perforation, external nasal deformity, and persistent nasal obstruction. Conventional septoplasty can also lead to nasal septal instability and postoperative nasal septal deviations (Siegel *et al*., 2000).

Conventional septoplasty is usually performed under general anaesthesia or under i.v. sedation, leading to significant hospitalisation costs. There is also significant pain. In a UK study (Chidambaram *et al*., 2001) of a postal survey of patients, postoperative pain was the most common reason for a delay in returning to work.

More than 90% of patients who underwent laser-assisted surgery for obstructing spur, in both our series and that reported by Kamami *et al*. (1997; 2000), reported subjective improvement of symptoms at the one-year follow-up. Most of our patients had little or no postoperative pain and were able to return to work the same day. No complications were encountered in our series.

As the laser reshaping procedure evolves, it is likely that nasal obstruction due to deviated nasal septum will be managed with non-surgical modality (Velegrakis *et al*., 2000).

9. Results

The surgical outcome is independent of the laser wavelength used. Generally, most patients are satisfied with an office-based procedure that spares general anaesthesia (Kamami *et al*., 2000; Kizhner *et al*., 2010). Septal haematoma or perforation has not occurred in any of the patients. Crusting is minimal with saline irrigation and appropriate debridement. Packing is not necessary. If adhesions form they can be easily addressed during the follow up visit in the office.

As for the septal reshaping technique, about 200 patients (cumulative number) were treated by this method without observed complication. Only one patient needed a revision by conventional surgery.

10. Conclusions

Spur reduction or ablation can be performed in the office setting avoiding general anaesthesia. Benefits include avoidance of potential complications of classic septoplasty (septal perforation and septal haematoma).

Using laser technology, complications such as bleeding and crusting are minimal and can be addressed easily. The common lasers for this approach can be the CO_2 laser which is limited to anterior spurs or a diode laser which is easily manoeuvred towards the nasopharynx, thus treating posterior spurs as well.

An evolving approach includes heating the septum with a holmium:YAG laser or an Erbium doped glass fibre laser for septal reshaping with a specially designed speculum.

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MCQ – 53. Laser-assisted septoplasty

1. Commonly used laser/s for removal of septal spur is/are
   a. CO_2 laser
   b. Diode laser
   c. Ho.YAG laser
   d. Er.Glass fibre laser
   e. KTP laser

2. Advantages of diode laser are
   a. Fibre transmissibility
   b. Affinity of the wavelength to cartilage
   c. Ability to destroy hard tissue such as the bone
   d. Cost effectiveness
   e. No postoperative bleeding

3. Laser thermal cartilage reshaping involves
   a. Open surgical procedure, using laser to remove and reshape cartilage
   b. Thermal relaxation of stress
   c. Thermal enhancement of stress
   d. Thermal shrivelling of cartilage to new shape

Chapter 54

Laser midline glossectomy and lingualplasty for obstructive sleep apnoea syndrome

J. Krespi, V. Kizhner and A. Kacker

1. Introduction

Laser surgery can be undertaken in selected cases of OSAS when the obstruction is located at the base of the tongue, hypopharynx, or supraglottic tissue. Ideally, surgery should remove all sleep related airway obstructions. However, in the majority of OSAS cases, this is not achievable. Woodson and Fujita (1994) reported a reduction of 50% in the RDI in 42% of their patients. Reversal of tracheostomy was possible in many patients following midline glossectomy (MLG) (Fujita *et al*., 1991).

Woodson and Fujita (1994) advocate surgery in a staged fashion, the technique with the least morbidity being carried out first. This is followed by surgery with increasing morbidity but which, when aggressively managed, can produce an acceptable outcome.

In most cases involving the base of the tongue, peri-operative tracheostomy forms an integral part of the surgical process. Contraindications for lingual surgery include patients with difficulty in swallowing and those with poor pulmonary function.

2. Surgical procedure

The aim of surgery is to remove excess tongue tissue for a given anatomical contour of the oropharynx and hypopharynx. A midline furrow is created in the tongue. A compromise must be found between adequate removal and the preservation of swallowing function.

Woodson and Fujita (1994) advocate the following procedure: Following tracheostomy, a mouth gag with the tongue blade one size shorter is inserted. A rectangular midline portion of the tongue, 2–2.5 cm wide and 4–5 cm long, is marked with methylene blue, posterior to the circumvallate papillae. A rectangular mucosal strip is removed. The incision in the tongue is deepened, and a wide strip of the tongue musculature is removed by traction and vaporisation. Fair sized branches of the lingual artery are encountered. These are ligated, or sealed off with diathermy. Further tissue vaporisation, particularly in the vallecula, is not possible with the mouth gag. Therefore, a laryngoscope is introduced and removal by vaporisation of any obstructing soft tissue in the vallecula, epiglottis, and arytenoid area, is carried out. The lingual tonsils are removed. A detailed description of lingual tonsillectomy is included in Chapter 47.

On completion of the removal of all the obstructing soft tissue, the mouth gag is replaced and lingualplasty is performed. A superficial wedge of the tongue is removed on each side, lateral to the anterior end of the rectangular defect created by the midline glossectomy. 2-0 Vicryl suture is used to pull and collapse the posterior tongue anteriorly and laterally into the defect of the midline glossectomy. It is then stitched to the wedge-shaped mucosal defect created earlier, in order to modify the shape of the tongue base.

Intensive swallowing exercises are given post-operatively. Problems of aspiration are addressed in the same way as for supraglottic laryngectomy. The

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procedure is technically difficult and requires experience and intensive postoperative care. Tracheostomy adds to the morbidity and prolongs hospitalisation.

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MCQ – 54. Laser midline glossectomy and lingualplasty for obstructive sleep apnoea syndrome

1. Midline glossectomy is advocated
    a. For patients who have difficulty in swallowing
    b. For severe cases of snoring
    c. For obstructive sleep apnoea syndrome where enlarged base of the tongue is a contributory factor
    d. For patients who need tracheostomy to manage obstructive sleep apnoea syndrome
    e. For patients who have a poor pulmonary function

2. Preoperative tracheostomy
    a. Is not always necessary, if ICU facilities are available
    b. In the absence of adequate ICU facility, tracheostomy forms an integral part of the operative procedure for midline glossectomy
    c. Is performed if there is postoperative aspiration
    d. If there is excessive intraoperative bleeding
    e. Increases overall morbidity

3. Midline glossectomy operation
    a. Should be part of the overall management strategy in cases of obstructive sleep apnoea syndrome
    b. Requires experienced surgeon
    c. Requires intensive postoperative care
    d. The procedure is association with a considerable morbidity
    e. All of the above

4. Midline glossectomy can be performed
    a. Trans orally
    b. Trans-cervical
    c. With TORS (trans oral robotic surgery)
    d. All of the above

Section VIII: Lasers in Lower Airways

SECTION VIII: Lasers in Lower Airways

Section Editor: A. Mehta

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Y. El-Sameed and A. Mehta

Chapter 55

Lasers in the lower airways

Y. El-Sameed and A. Mehta

Part A: Photoresection for lower airway lesions

1. Introduction

Although laser technology has been used in the field of medicine since the early 1960s, its application in the respiratory tract is not wide spread. The first clinical application of the CO_2 laser in the lower airways was reported by Strong *et al.* in 1973. In 1979, Godard *et al.* first used the Nd:YAG laser in the endobronchial tree. Subsequent reports demonstrated effectiveness and safety of lasers in the tracheobronchial tree (Laforet *et al.*, 1976; Toty *et al.*, 1981; Dumon *et al.*, 1982; Kvale *et al.*, 1985). Today, laser bronchoscopy has become a comparable alternative to some major surgeries (Fig. 1), and has evolved to be a major instrument in the palliation and improvement of the quality of life in patients with terminal diseases.

Several types of laser have been used in the respiratory tract, and their characteristics are described in Table 1. The most common lasers used for the lower airways are the CO_2 and the Nd:YAG. The CO_2 laser beam is directed towards the lesion by a series of mirrors in the joints of an articulated arm, limiting its use to rigid bronchoscopy (RB). It is presently used more for lesions involving the larynx and proximal trachea (Rebeiz *et al.*, 1996). Moreover, the CO_2 laser wavelength is strongly absorbed by water and does not allow deep tissue penetration. Treatment of vascular lesions is difficult with the CO_2 laser, as it does not produce haemostasis when the blood vessels are greater than 0.5 mm in diameter (Shapshay *et al.*, 1983). The Nd:YAG laser does not have these limitations and thus has become the preferred instrument for the lower airways (Ramser and Beamis, 1995). The Nd:YAG laser beam can be passed through a flexible endoscope via a pliable quartz filament. It affords deeper penetration, allows better coagulation, and produces better haemostasis of blood vessels. Its main disadvantage is the unpredictable interaction of the laser beam with the tissue, making it difficult to determine the depth of penetration. Other laser wavelengths, which have been clinically used in the endobronchial tree, include the argon (Gillis *et al.*, 1983; Hetzel *et al.*, 1985; Rimell, 1997), and potassium titanyl phosphate (KTP) (Ward, 1992; Rimell, 1997). The advantage of these lasers is that the wavelength can be passed through a very thin quartz fibre (200 µm), which makes them useful in paediatric patients (Ward, 1992; Rimell, 1997). However, the argon laser has fallen into disuse since it produces a weaker beam, unpredictable soft tissue interaction, and poor wound healing (Gillis *et al.*, 1984). Moreover, in experimental canine models, the rate of tracheal perforation was determined to be unacceptably high with argon lasers (Gillis *et al.*, 1983).

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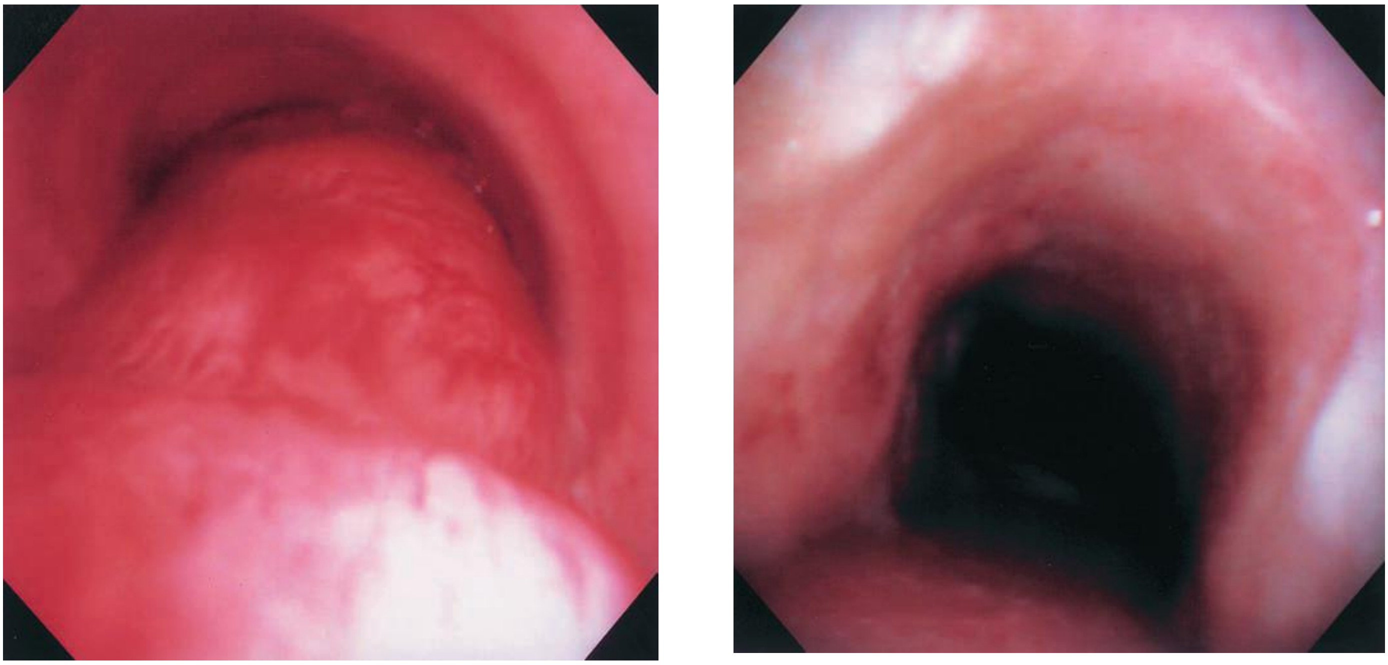

Fig. 1. Tracheal cystic adenoid carcinoma before (left) and after (right) Nd:YAG laser photoresection. (Reproduced from Seshadri *et al.* (1999) by courtesy of the *Journal of Bronchology*.)

The new neodymium-yttrium-aluminium-perovskite (Nd: YAP) laser has a wavelength of 1340 nm. It has good coagulation properties making it effective in restoring airway patency from malignant obstruction. The unit is portable and easy to use (Acash *et al.*, 2009).

Diode laser has been recently used in airway procedures (Fanjul M *et al.*, 2008). Its media is composed of small semiconductor chip (solid-state laser). This makes the diode laser machine smaller and easier to transport than other machines. Its solid media makes it also reliable.

2. Instrumentation

2.1. Rigid versus flexible bronchoscope

Laser photoresection (LPR) can be performed through a rigid (RB) or a flexible bronchoscope (FB). Factors influencing the selection of the instrument are described in Table 2. RB allows easier ventilation, better suction and airway control, and the ability to debulk larger tissue fragments. Its use is also preferred in the treatment of vascular lesions, as it allows the simultaneous application of ventilation, suction, and photocoagulation. Unfortunately, the number of physicians formally trained in RB has dramatically declined in the USA (Prakash and Stubbs, 1991), thus limiting its applicability.

The main advantage of LPR with an FB is that it enables distal airway lesions to be reached and provides better control and precision in directing the laser beam. However, LPR via an FB can be more time-consuming, as only smaller pieces of debris and tumour can be removed at a time. In our practice, the procedure time has been reduced by the use of a Fogarty's catheter, flexible scissors, polypectomy snare, and a 'Dormia' basket to debulk the tumour.

In skilful hands, Nd:YAG laser resection through either an RB (Shapshay *et al.*, 1983; Perrin *et al.*, 1992) or an FB (Toty *et al.*, 1981; McDougall and Cortese, 1983; Joyner *et al.*, 1985) is safe and effective. Chan *et al.* (1990) found the survival and complication rate of laser therapy using an RB or an FB to be similar. In general, selection of the bronchoscopic instrument depends on the comfort and technical expertise of the operator. In our opinion, both methods are complimentary. Our preference has been mainly to use an FB, while having an RB as a back-up in the event of significant bleeding. We feel that a

Table 1. Comparison of the different types of laser used in the tracheobronchial tree

	CO_2	*Nd:YAG*	*Argon*	*KTP*	*Nd:YAP*	*Diode*
Wavelength (nm)	10,600	1064	488-514	532	1340	810
Bronchoscope system	rigid	rigid or flexible	rigid or flexible	rigid or flexible	rigid or flexible	rigid or flexible
Tissue absorption	high	low	Selective: high in blood	Selective: high in blood	low	Selective: pigmented structures
Tissue penetration (mm)	0.1	4	1	1	4	2-3
Coagulation	low	high	medium	medium	medium	medium
Cutting effect	high	low	low	low	unknown	low

Table 2. Selection of rigid versus flexible bronchoscope for Nd:YAG laser photoresection

Factors	*Rigid bronchoscope*	*Flexible bronchoscope*
Expertise	thoracic surgeon otorhinolaryngologist	pulmonologist
Laser type	CO_2, Nd:YAG, argon, KTP	Nd:YAG, argon, KTP, Nd:YAP, Diode
Time commitment	short	long
Anaesthesia	usually general; local can be difficult	general or local
Management of bleeding	easier	can be difficult
Special considerations		
location of lesion	proximal airways	distal airways
cervical spine deformity	contraindicated	treatment possible
maxillofacial injury	contraindicated	treatment possible
endobronchial ignition	less likely	possible

Table 3. Modes of ventilation during Nd:YAG laser photoresection

Bronchoscope	*Rigid*		*Flexible*			
Location of the lesion	all lesions		larynx and upper trachea		lower trachea and main bronchi	
Anaesthesia	usually general	general	local	general	local	general
Modes of ventilation	spontaneous	apnoeic oxygenation apnoea and intermittent ventilation Venturi jet closed mechanical high-frequency positive-pressure	spontaneous	laryngeal mask airway Venturi jet via metal cannula modified endotracheal tube*	spontaneous	endotracheal tube

*see text

working knowledge of the use of an RB is desirable, but not mandatory if surgical back-up is readily available.

3. Ventilation and anaesthesia

LPR can be performed using a variety of techniques for maintaining oxygenation and ventilation (Eisenkraft *et al.*, 1997). These are shown in Table 3. LPR can be performed under conscious sedation (CS); however, the cough reflex, which is seldom completely abolished, can become a significant problem and can easily cause laser beam misdirection. Excessive smoke production or bleeding can also frighten the patient. Moreover, on occasion, the procedure may take two to three hours, and it may be difficult for a semi-conscious patient to cooperate for that duration. Most operators prefer to perform LPR under general anaesthetic (GA) (McElvein and Zorn, 1983; Beamis *et al.*, 1991; Cavaliere *et al.*, 1996), since this provides a controlled environment with good muscle relaxation.

The risks from general anaesthesia are small and include respiratory failure (0.5%), cardiac arrest (0.4%) and acute myocardial infarction (0.2%) (Cavallieri *et al.*, 1994).

For LPR of lower tracheal or bronchial lesions using an FB, we use conventional ventilation through the largest possible size of polyvinyl chloride (PVC) endotracheal tube (ET) compatible with the patient's airway, for greater manoeuvrability of the FB (Mehta *et al.*, 1995b). The cuff of the ET is placed close to the vocal cords in order to maintain maximum distance between the lesion and the tip of the flammable tube. Saline instead of air is also used to inflate the cuff, and the ET is secured with a minimal amount of tape so that, in the rare case of endobronchial ignition, the tube can easily be removed and the saline may help to extinguish the initial flames.

With high tracheal and subglottic lesions, and paediatric cases in which the small airway size hampers the mobility of the FB in the ET, ventilation under general anaesthetic (GA) is provided via laryngeal mask airway (LMA) (Minai *et al.*, 1998; Holmström and Akeson, 1997). For midtracheal lesions, another option would be to cut off part of the ET distal to the cuff to increase the distance between the ET and the lesion. Silicone glue is applied to the distal end of the cuff channel to prevent leakage of air (Mehta *et al.*, 1995a).

LMA has been used more frequently during bronchoscopies as a safe and effective method for securing the airway (Sung *et al.*, 2007). Snow *et al.* (2004) evaluated the role of LMA in 70 bronchoscopies, both diagnostic and therapeutic. He found that LMA used in procedures that need general anaesthesia reduces the recovery time and creates less bronchospasm compared to endotracheal intubation.

4. Laser–tissue interaction

The effect of the laser beam on the tissue is affected by its power settings, its relation to the lesion, and by the tissue characteristics. Tissue effects can be modified by altering the power (watts) and duration of the laser pulse. Firing the pulse at shorter intervals also increases heat build-up in the lesion, causing increased destruction and vaporisation. However, power settings greater than 50 watts and a pulse duration of more than one second should be avoided as this may result in the explosion of deeper tissues ('popcorn effect'), causing damage to the airway wall and excessive bleeding. Furthermore, the chance of massive haemorrhage is increased when power settings greater than 40 watts are used (Brutinel *et al.*, 1987).

The divergence of the laser beam is 10° with a working focal length of 5-10 mm and a corresponding spot size of 1-2 mm (Dumon *et al.*, 1982). The term "power density" of a laser is defined as the power transmitted per unit area of cross-section of the laser beam (watts/cm^2). It is inversely proportional to the square of the diameter of the focal target (Fisher *et al.*, 1983). Moving the fibre tip away from the lesion will result in the energy being distributed over a wider area of the tissue, causing more coagulation and less tissue destruction. Moving the fibre closer to the lesion causes charring and vaporisation. Directing the laser beam perpendicular, rather than tangential, to the lesion will also create greater penetration.

With well-vascularised lesions, heat energy is carried away by the blood flow, thus resulting in less tissue damage. Pale tissues also absorb less light, allow less penetration, and produce as much as 40% more backscatter than darker tissues.

5. Surgical technique

With highly-vascularised lesions causing airway obstruction, vaporisation of the tumour tissue with minimal instrumentation is preferred. The lesion is vaporised layer by layer, starting with the most superficial region and subsequently working toward the base (Fig. 3). For less vascular lesions, mechanical

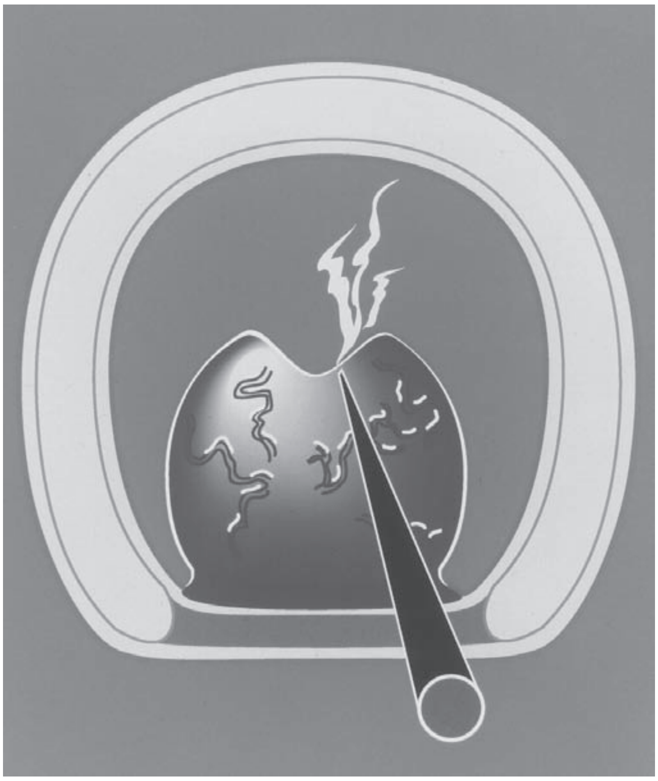

Fig. 3. Laser photoresection technique of a highly-vascularised obstructive lesions. (Reproduced from Mehta *et al.* (1995b) by courtesy of the publishers.)

debulking and the complementary use of a laser can lead to easier and rapid tissue removal. For polypoid lesions, a polypectomy snare can be used to cut the stalk after laser photocoagulation. Excised tissue is then removed by the use of forceps. Lesions larger than the working channel size of the FB can be removed by grasping the lesion with a forceps and then withdrawing the FB and the lesion as a unit from the ET. Lesions larger than the lumen size of the ET will require removal of the FB with the ET, and reintubation.

For non-obstructive vascular lesions where the goal is haemostasis, the laser energy is applied in a rosette pattern around the bleeding site in order to coagulate the feeder vessels.

To avoid airway damage, the laser beam is kept parallel to the tracheobronchial wall. A size 4 to 7 Fogarty catheter is useful for helping to identify the direction of the distal lumen. The catheter can also help to drag the tissue from the lobar bronchi into the proximal airway for its safe vaporisation. A non-contact method is used to photoresect an endobronchial lesion. This technique involves firing the laser beam at a distance from the lesion.

6. Indications and contraindications

Nd:YAG LPR is indicated for the treatment and palliation of large, surgically unresectable airway lesions (Table 4). The main goal of applying LPR to these tumours is to provide patients with symptomatic relief from shortness of breath, cough, wheezing, haemoptysis, and prevent post-obstructive pneumonia (Kvale PA *et al.*, 2007). In order to ensure maximum benefit from LPR, careful patient selection is needed (Table 5). Lesions located in the trachea or mainstem bronchi are easily treated by LPR, whereas the treatment of lobar or segmental bronchi is difficult and is associated with a higher complication rate. Cavaliere *et al.* (1996) reported a success rate of 92-97% for lesions of the trachea, and right and left main bronchus. The success rate for the distal airways was significantly lower (49% and 66% for the right and left upper lobes, respectively). Gelb and Epstein (1984) also reported success rates of 90%, 91%, and 67% for tracheal, right main, and left main bronchi lesions, respectively.

Absolute contraindications to LPR include the absence of endobronchial lesion (airway narrowing caused by extrinsic compression) and complete airway obstruction. The operator should also consider the functional status of the patient and the duration of life expectancy before embarking on the procedure. Involvement of the airway and the corresponding segment of the pulmonary artery by the tumour is a contraindication to LPR, for recanalisation of the airway will only lead to dead space ventilation (the presence of ventilation in the absence of perfusion); this may potentially worsen dyspnoea and hypoxaemia. Performing a ventilation/perfusion scan can help in making the decision regarding the potential benefit from LPR. CT evidence of contiguous involvement between the oesophagus and the bronchus also indicates a high risk of producing a tracheo-oesophageal fistula. LPR might be contraindicated in certain group of patients. These include patients with severe sepsis and those with coagulation and electrolyte disorders that cannot be corrected.

7. Benign tracheobronchial obstructive lesions

Although a number of benign lesions can be treated with LPR, the surgical outcome of some lesions is more favourable than that of others. The follow-

Table 4. Indications for laser therapy of the lower airways

Thermal effect	*Laser photoresection of obstructive airway lesions*
Malignant	bronchogenic carcinoma, metastatic neoplasm, carcinoid tumour
Benign	subglottic and tracheal stenosis, granulation tissues, broncholith, foreign body, benign tumours, congenital tracheo-oesophageal fistula
Photochemical effect	
Photodynamic therapy	curative therapy for carcinoma *in situ*, juvenile laryngotracheobronchial papillomatosis, unresectable early stage lung cancer palliative treatment for advanced obstructive lung cancer
Autofluorescence bronchoscopy	localisation of carcinoma *in situ* and superficial bronchogenic cancer

Table 5. Factors that influence the outcome of Nd:YAG laser photoresection

Factors	*Favourable*	*Unfavourable*
Type of lesion	endobronchial	extrinsic
Appearance	polypoid, pedunculated	exophytic, submucosal
Extent of involvement	localized (one wall)	extensive (>1 wall)
Length of lesion	<4 cm	>4 cm
Distal lumen	visible	not visible
Duration of lung collapse	<4-6 weeks	>4-6 weeks
Clinical status		
haemodynamics	stable	unstable
oxygenation requirement	<40% FiO_2	>40% FiO_2
coagulation profile	normal	abnormal
Pulmonary vascular supply	intact	compromised

ing discussion reviews the literature and describes the authors' experience in the application of LPR.

7.1. Subglottic and tracheal stenosis

Subglottic and tracheal stenosis can be either congenital or acquired. Acquired stenosis is usually secondary to trauma from endotracheal intubation and tracheostomy. With the number of endotracheal intubations and emergency medical procedures increasing, subglottic and tracheal stenosis have become common clinical problems. On occasion, systemic diseases (*i.e.*, amyloidosis, papillomatosis, Wegener's granulomatosis, tuberculosis, and polychondritis) can also cause such narrowing.

Traditionally, the majority of these patients required either surgical resection and/or tracheostomy and stenting. Consideration should be always given to possible open surgical resection of the stricture and reanastomosis (Couraud *et al.*, 1988). Many patients are not good candidates for surgical resection because of medical co-morbidity, severe cardiopulmonary illness and high anaesthetic risk, or the characteristics of the stricture such as its length. In these patients, bronchoscopic options should be considered. Endoscopic management of the subglottic stenosis involved dilatation with either Jackson dilators or the RB (Hawkins, 1977). The process was laborious, requiring multiple dilatations over an eight-week period, and was often unsuccessful. Subsequently, the CO_2 laser was used to completely vaporise scar and granulation tissues (Koufman *et al.*, 1981). Even with the addition of stents after vaporisation, the long-term patency rate was disappointing. Most if not all successfully treated patients required multiple repeat procedures. In some cases, appearance of granulations following removal of stents made the condition worse.

With the help of laser techniques, selected tracheobronchial stenosis can now be safely treated endoscopically (Table 6). Concentric-web or diaphragmatic-type strictures of less than 1 cm in vertical length are the most suitable for treatment. Multiple webs, circumferential scarring with cicatricial contracture (Simpson *et al.*, 1982; Ossoff *et al.*, 1985), concomitant tracheomalacia (Simpson *et al.*, 1982; Mehta *et al.*, 1993), carinal involvement (Ossoff *et al.*, 1985), stenosis involving both the larynx and trachea, and a history of bacterial infection associated with a tracheostomy (Simpson *et al.*, 1982), are usually associated with poor outcome. In patients with unfavourable anatomical findings, lengthy stenosis and cricoid cartilage deformities, open repair or reconstructive surgery may be a better option.

From earlier experience, it is apparent that minimising mucosal trauma is essential for preventing recurrence. Damage to the mucosa at the stenotic site may predispose to disorganised healing, excessive fibrous tissue proliferation, and scar recurrence. Alternative 'mucosal sparing' techniques were devised to limit post-laser scar formation and to provide an organised nidus for tracheal epithelial restructuring. In 1984, Dedo and Sooy used the CO_2 laser to raise mucosal flaps and vaporise underlying scar

Table 6. Features of tracheal and subglottic stenosis associated with poor outcome

Scarring longer than 1 cm in length
Bottle-neck or hourglass type strictures
Tracheomalacia
Circumferential scarring with cicatricial contracture
History of bacterial infection associated with tracheotomy
Carinal involvement of the stenosis
Combined laryngeal and tracheal stenosis
Cricoid cartilage deformity

tissue. The epithelial flap, acting as a biological tissue dressing, was then placed back in its original position. Success was reported in 90% of patients with subglottic or tracheal stenosis less than 1 cm long. In 1987, Shapshay *et al*, used the Nd:YAG or CO_2 laser to introduce radial incisions coupled with dilatation. These radial incisions were made through the epithelium and the underlying fibrous tissue using intermittent exposures of laser energy. Islands of normal epithelium between the radial laser incisions were preserved, allowing rapid normal epithelialisation of the respiratory tract. Long lasting success was noted in three of five patients at the end of a one-year follow-up period. A subsequent follow-up report using silicone T-tube stents with multiple radial incisions and increasing rigid bronchoscopic dilatations showed success in eight of 12 (67%) tracheotomy patients with total cervical stenosis (Shapshay *et al.*, 1989).

In 1993, the authors reported the successful treatment of tracheal and subglottic stenosis in 12 of 18 patients (67%) using a mucosal sparing technique with Nd:YAG LPR and gentle dilatation without stenting (Mehta *et al.*, 1993). The laser was used to produce radial incisions through the entire vertical length of the stenotic lesion, usually at the 9, 12 and 3 o'clock positions (Fig. 5). In order to avoid scar recurrence, minimal laser energy was used to avoid trauma to the surrounding tissue. Average power settings of 30-40 watts with an 0.4-second pulse duration were used in most cases. Following LPR, gentle dilatation was achieved by using a size 7-, 8- or 9-mm RB. Unlike routine dilatation with increasing sizes of bougies or rigid bronchoscopes, gentle dilatation consisted of a single insertion of the largest possible RB that the patient's trachea could accommodate. This minimised mucosal injury by mechanical trauma from repeated insertions over the treatment site. Significant trauma to the mucosa, causing exposure of the perichondrium, can cause increased inflammation and chondritis. An alternative technique is to dilate the stenotic site with a valvuloplasty or angioplasty balloon catheter after radial incisions with a laser (Noppen *et al.*, 1997; Carlin *et al.*, 1988). The balloon is guided into position with a fluoroscope and is inflated to its near maximal pressure for two to three minutes, or whenever hypoxemia occurs. In most cases, this is an outpatient procedure (Mehta *et al.*, 1995a).

Endobronchial electrocautery (EBEC) can be used to treat patients with benign airway obstructive lesions. In a study done to evaluate the impact of EBEC on the need for LPR, EBEC was performed safely and effectively in the outpatient setting and eliminated the need for LPR in 36% of the cases (Coulter TD *et al.*, 2000). Tremblay A *et al.* (2003) reported successful results using EBEC and balloon dilation to manage web-like benign airway stenosis bronchoscopically.

The use of corticosteroids (systemic or local) and antibiotics have not been adequately studied to determine its role during endoscopic manage ment of airway stenosis. Steroids can delay epithelialisation and healing. Koufman *et al.* (1981) routinely used systemic steroids prior to LPR, and subsequently performed local injection of steroids intraoperatively in the hope of reducing postoperative oedema. Shapshay and co-workers (1989) avoided the use of steroids for fear of delayed epithelial migration and increased risk of infection. The authors use corticosteroids only if significant postoperative laryngeal oedema is expected. They also prescribe oral corticosteroids following the procedure in patients with chronic obstructive pulmonary disease (COPD) since mechanical manipulation of the airway can precipitate an exacerbation in these patients.

The possibility of infection after the procedure has prompted the use of prophylactic antibiotics. In animal models, infection was shown to predispose scar tissue formation and airway stenosis (Sakasi *et al.*, 1979). The amount of scar tissue produced was found to be directly related to the length of time required for wound healing and to the presence of localised infection. Based on this work, several groups have suggested the prophylactic use of antibiotics (Simpson *et al.*, 1982; Friedman *et al.*, 1983; Shapshay *et al.*, 1987). Moreover, Koufman *et al.* (1981) used parental antibiotic therapy based on perioperative stomal and subglottic cultures. Infection rates and the effect of antibiotics on procedure success have not been analyzed in any of these investigations. Pending further data the authors do not use

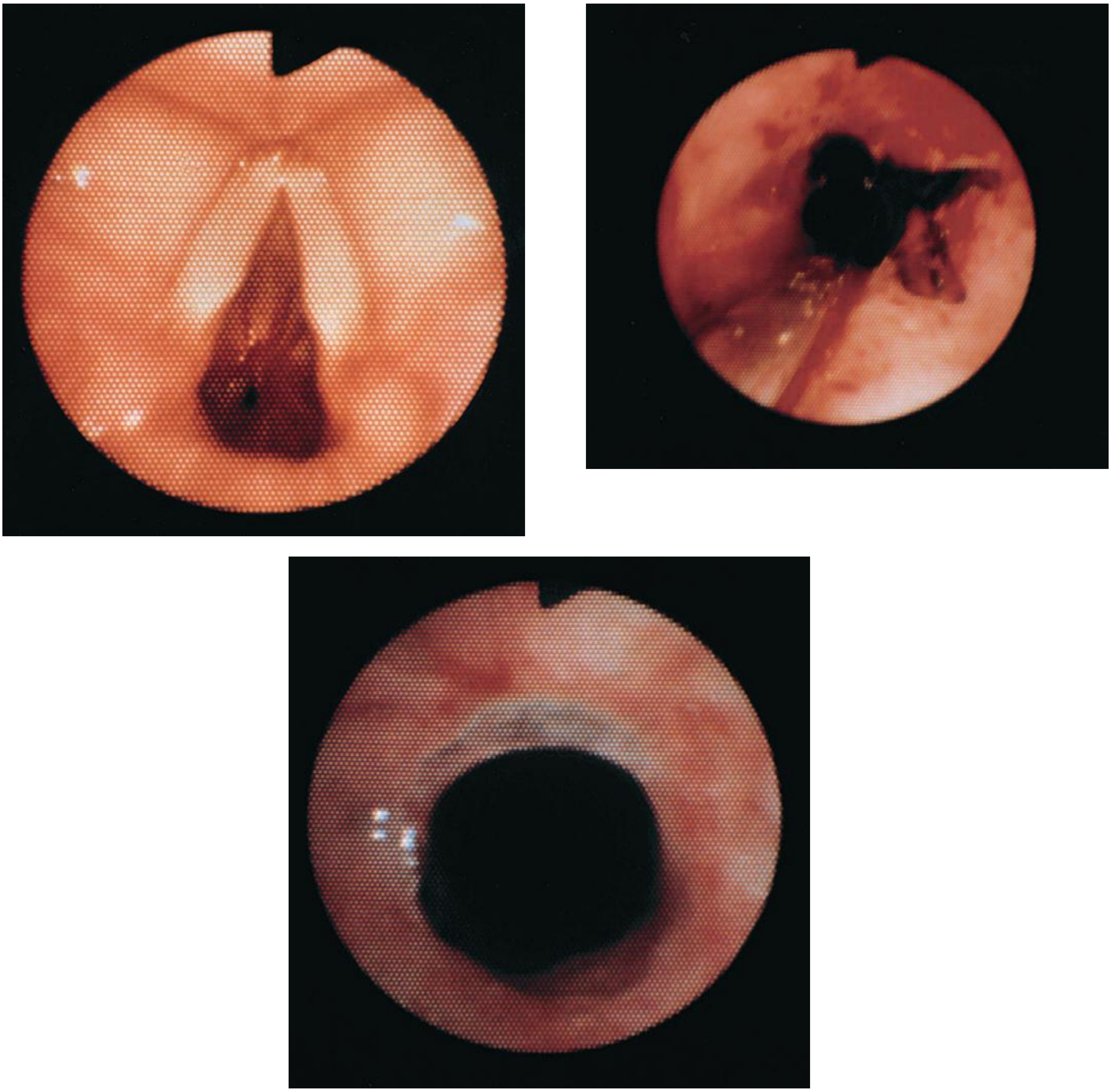

Fig. 5. Radial incision and gentle dilatation of a concentric subglottic stenosis allowing for organised healing and rapid re-epithelialisation. (Reproduced from Mehta *et al*. (1993) by courtesy of *Chest*.)

prophylactic antibiotics routinely, but reserve their use only in cases with significant mucopurulent secretions noted during the procedure.

Re-evaluation is usually performed at six weeks, unless symptoms recur. In some cases, a repeat procedure may be necessary. In our practice, the number of treatments is limited to three. If stenosis recurs following the third endoscopic treatment, the patient is referred for tracheal re-construction.

7.2. Endobronchial granulation tissues

Granulomas can result as a reaction of the tracheobronchial mucosa to a foreign body (*e.g.*, tracheostomy tube, endotracheal tube, transtracheal oxygen catheter, or suture material from previous endobronchial surgery). When such granulomas become symptomatic, they can be easily removed by LPR (Dumon *et al.*, 1982; Gregor, 1988; Beamis *et al.*, 1991). In particular, symptomatic obstruction by granulation tissues at the anastomosis site can frequently occur after lung transplantation. LPR is very effective in these settings (Colt *et al.*, 1992; Sonett *et al.*, 1995; Madden *et al.*, 1997).

If LPR is done to remove granulation tissue caused by a stent, care should be taken to avoid fire ignition in case of silicone stents and breaking the wires in case of metallic stents (Dalupang JJ *et al.*, 2001).

7.3. Broncholiths

A broncholith is a calculus or concretion in the endobronchial tree, usually resulting from the erosion of a calcified lymph node into the tracheobronchial tree. Occasionally, broncholiths can cause symptomatic airway obstruction. By means of a forceps through a bronchoscope, small broncholiths can easily be removed. With a large broncholith, open-chest surgery would be needed. However, with the use of a laser, the broncholith can be fractured into pieces, and the surrounding granulation tissue can be vaporised, thus facilitating removal (Faber *et al.*, 1975; Miks *et al.*, 1986).

7.4. Foreign bodies

Similarly, a foreign body can easily be removed endoscopically. When it is of substantial size, LPR can be used to vaporise the surrounding granulation tissue and break the foreign body, allowing piecemeal removal (Unger, 1985).

7.5. Benign tumours

Benign tumours causing airway obstruction can also be easily removed by LPR. The successful removal of haemangiomas, lipomas, myoblastomas, chondromas, leiomyomas, histiocytomas, papillomas, adenomas, lipomas, angiomas, leiomyomas, schwannomas, neurofibromas, amyloidomas, fibromas, hamartochondromas, and hamartomas has been reported in the literature (Dumon *et al.*, 1982; Personne *et al.*, 1986; Shah *et al.*, 1995). Total patency can often be achieved. Repeated treatments are sometimes necessary, since some of these lesions recur, but prognosis is good, given their benign nature.

7.6. Tracheo-oesophageal fistulas

In a rat model, Meier (1986) showed that the Nd:YAG laser could close the oesophagus by welding or coagulating the mucosal walls. By using power settings of 16 and 22 watts for less than two seconds, perforation of the oesophagus was avoided. Schmittenbecher *et al.* (1992) performed Nd:YAG laser photocoagulation on three newborns with congenital tracheo-oesophageal fistulas. A bare, uncovered quartz fibre of 600 μm was passed into the fistula. Power settings between 10 and 15 watts and a duration of 0.5-1 second were used. Successful treatment was achieved in two cases. The incomplete obliteration in the remaining case was thought to be due to inadequate energy application.

7.7. Wegner's Granulomatosis (WG)

WG can affect the airways, particularly the subglotic area. This can be in the form of active inflammation and edema, or formation of fibrous tissue and airway strictures (Kupeli E *et al.*, 2002). LPR of these strictures is usually challenging, and may require stenting to prevent recurrence.

8. Malignant tracheobronchial obstructive lesions

It is necessary to appreciate that some LPR applications for malignant obstructions are used as a palliative measure rather than a cure. The following discussion covers the LPR applications in the management of these lesions.

8.1. Carcinoid tumours

Carcinoid tumours are low-grade malignant tumours arising from the argentaffin cells. LPR should not be used as the primary therapy since recurrences with metastasis are common. LPR should only be used for the palliation of unresectable tumours (Dumon *et al.*, 1982; McDougall and Cortese, 1983; Brutinel *et al.*, 1987; Diaz-Jimenez *et al.*, 1990) or to limit the extent of lung resection (Mehta *et al.*, 1999; Schepens *et al.*, 1994; Sutedja *et al.*, 1995). In Okike *et al.* (1976)'s series of 203 patients with typical bronchial carcinoid tumours, pneumonectomy was commonly performed due to suppuration distal to the obstruction. In selected cases, a laser can be used to relieve the obstruction, enabling adequate treatment of the suppuration with antibiotics. This may allow preservation of uninvolved lung tissues by confining the surgery to lobectomy instead of pneumonectomy.

8.2. Bronchogenic carcinomas

LPR has been shown to be an effective and safe tool in the palliation of symptoms (*i.e.*, cough, dyspnoea, haemoptysis, post-obstructive pneumonia, etc.) due to endobronchial bronchogenic cancer (Toty *et al.*, 1981; Dumon *et al.*, 1982; Kvale *et al.*, 1985; Cavaliere *et al.*, 1996). In Cavaliere *et al.* (1996)'s series of 2610 laser treatments in 1838 patients, radiographic and endoscopic improvement was seen in 93% of patients with bronchogenic carcinoma with consequent improvement in the quality of life. Hetzel *et al.* (1985) reported symptomatic improvement in 64% of patients with advanced tracheobronchial tumour, most of whom had failed chemotherapy or radiotherapy. In patients with partial obstruction, improvement was noted in 76%. Re-expansion of a collapsed lung was achieved in 29%. LPR can also be effective in very advanced cases. Stanopoulos *et al.* (1993) reported the successful weaning and extubation of nine of 17 ventilator-dependent patients after LPR of an endobronchial tumour.

Daddi G *et al.*, (1998) described the role of preliminary endoscopic relief of airway obstruction to potentially increase operability and improve surgical resection in a highly selected group of patients.

The current literature contains no data prospective to establish the role of laser therapy with regard to other available modalities (*i.e.*, radiotherapy, chemotherapy, brachytherapy, cryotherapy, and electrosurgery) in the treatment and palliation of end-stage lung cancer. As far as we know, no randomised trial has been performed to compare LPR with alternative methods of treatment for end-stage lung cancer. In 1985, Jain *et al.* showed that patients who were initially treated with laser therapy prior to radiation therapy sustained airway patency, better performance status and survival compared to historical controls receiving palliative external beam radiation alone. This suggests that the initial relief of airway obstructions by laser therapy improves the patients' ability to tolerate subsequent external radiation treatment. A similar study by Macha *et al.* (1994) failed to show any survival benefit with LPR; however, a subset of patients with successful LPR airway recanalization did have an increased survival of four months. Similarly, Eichenhorn *et al.* (1986) showed greater survival in patients with successful LPR compared to those with unsatisfactory results (median survival of 340 days versus 39 days, $p <$ 0.006). Moreover, no significant improvement in survival was shown between patients who did or did not have LPR in addition to palliative radiotherapy (Desai *et al.*, 1988). However, in the subgroup of patients who needed emergency LPR, survival was higher ($p = 0.04$) when compared to historical controls who only received emergency radiotherapy. We concluded that patients with critical endobronchial obstruction will generally do better if they undergo LPR prior to radiotherapy. If LPR is done for palliation of a malignant lesion, small amounts of tumour may be left in the airway at the end of the procedure. Attempting to "perfect" the ablation by remove the entire tumor may end up causing injury to the airway wall unnecessarily. Moghissi K *et al.*, (1997) studied sequential Nd:YAG laser therapy in patient with malignant airway obstruction followed 6 weeks later by photodynamic therapy. All 17 patients had symptomatic relief and at least a

Table 7. Incidence of complications following laser photoresection

Author	*No. of treatments*	*Vessel perforation*	*Endobronchial ignition*	*Pneumothorax*	*Haemorrhage*	*Arrhythmias/ myocardial infarction*	*Death*	*Complications (%)*
Dumon *et al.* (1982)	1503	1	0	4	14	3	1	0.34
Kvale *et al.* (1985)	82	0	0	0	0	1	1	0.01
Personne *et al.* (1986)	2289	3	0	24	–	–	18	1.18
Brutinel *et al.* (1987)	176	3	0	1	10	0	3	2.27
Mehta *et al.* (1995b)	330	1	1	5	5	2	4	2.12
Cavaliere *et al.* (1996)	2610	0	0	8	19	5	12	0.03
Venuta *et al.* (2002)	351	0	0	0	7	0	3	2.85
Hujala *et al.* (2003)	270	0	0	0	20	0	2	8.15
Total	7611	8	1	42	75	11	44	2.12

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Table 8. 'Rule of Fours' for safe and successful outcome of Nd:YAG laser photoresection through flexible bronchoscopy

Initial settings	
power	40 watts
pulse duration	0.4 seconds
Distances	
endotracheal tube to lesion	>4 cm
fibre tip to lesion	4 mm
FB to fibre tip	4 mm
Distances	
ET to lesion	>4 cm
fibre tip to lesion	4 mm
FiO_2 during LPR	<40%
Number of pulses between cleaning	40
Maximum length of lesion	4 cm
Duration of collapse	<4 weeks

partial response. Seven had a complete response for 3-6 months. Van Bosem *et al.* (1999) performed a retrospective study to compare Nd:YAG laser versus bronchoscopic electrocautery for palliation of symptomatic malignant airway obstruction. Both groups had similar improvement of symptoms and similar survival, however, electrocautery was cheaper than LPR.

8.3. Metastatic neoplasms

Neoplasms from renal, breast, thyroid, and colon cancer are the most common malignancies associated with tracheobronchial metastases. Although these patients have a very poor prognosis, effective palliation of airway obstructions can often be achieved (Shapshay and Strong, 1982; Carlin *et al.*, 1989, Cavaliere *et al.*, 1996). There is no significant difference between the responses of primary and metastatic endobronchial tumours treated with LPR (Desai *et al.* 1988; Fujisawa *et al.*, 1992). Lasers have also been used to treat oesophageal carcinomas that have invaded and obstructed the trachea, with improvement in the quality and duration of life in selected patients (Rebeiz *et al.*, 1992). Other rare metastatic tumours effectively treated include melanomas (Andrews and Caldarelli, 1981; Nicolai *et al.*, 1991), esthesioneuroblastoma (Franklin *et al.*, 1987), pheochromocytoma (Sandur *et al.*, 1999), and thymic, laryngeal, testicular, ovarian and bone cancers (Cavaliere *et al.*, 1996). Successful endoscopic laser treatment of endobronchial endometriosis has been described (Puma *et al.*, 2003).

9. Patient risk and benefits

In careful and experienced hands, LPR is a relatively safe procedure with a reported mean complication rate of 2.12%. The frequency and type of complications reported in eight large series are listed in Table 7. Overall mortality rate from LPR is 0.6%.

The most common complication is haemorrhage. Most neoplastic tumours are vascular and can potentially bleed during LPR. Minor bleeds can easily be controlled by cauterization with the Nd:YAG laser. With major bleeds (250-500 ml), a rigid bronchoscope will often be needed to tamponade the lesion, remove the clot and establish ventilation. Perforation of a major intrathoracic blood vessel is also a feared and most often fatal complication (McDougall and Cortese, 1983; Mehta *et al.*, 1995b). Prior to LPR, either CT or magnetic resonance imaging can easily establish the relationship of the airways and the intrathoracic blood vessels. These imaging studies are often beneficial in patients with a prior history of surgery or radiotherapy, in whom the normal anatomy can be distorted. Adherence to the recommended power settings dramatically decrease the chance of significant bleeding.

Pneumothorax is the second most reported complication of LPR. This complication seems to be secondary to mechanical ventilation rather than LPR (Unger, 1985). Pneumothoraces seem to occur more frequently with the use of jet ventilation. Peak airway pressures should be routinely measured when using jet ventilation in order to prevent inadvertent high pressures. Keeping the laser beam parallel to the bronchial wall can prevent laser-induced pneumothoraces.

Cardiovascular consequences (arrhythmias, myocardial infarctions, bradycardia, shock, cardi-ac arrest) during LPR have also been reported. These are thought to be related to the anaesthetic agents (Dumon *et al.*, 1984). Endobronchial ignition is an uncommon yet feared complication of LPR (Krawtz *et al.*, 1989; Schramm *et al.*, 1981; Denton *et al.*, 1988). ETs and FBs are both combustible and can ignite during the procedure, causing severe burns. Scherer TA (2000) studied various silicone stents and outlined the conditions that can cause airway fire. He showed that the lowest oxygen concentration to allow ignition of some stents was 40%. To avoid this complication, we have developed the 'Rule of Fours' (Table 8). The fraction of inspired oxygen is kept below 40% during application of the laser beam. The cuff of the ET is placed close to the vocal cords to maximise distance between the lesion and the end of the ET (at least 4 cm). The laser fibre should extend at least 4 mm from the tip of the bronchoscope, and be kept at least 4 mm from the lesion. After 40 pulses, the fibre is removed and its tip cleaned, since the presence of blood or debris will increase laser light absorption, which may lead to ignition (Krawtz *et al.* 1989) or loss of the laser fibre tip (Mehta and Grimm, 1988). By paying careful attention to these techniques, endobronchial ignition can be prevented. The initial management of airway fire consists of removing the flexible bronchoscope, the laser fibre, and all combustible materials from the airways. The airways should be then examined carefully and any foreign material removed. This step is essential to estimate the degree of the airway burn and organize further care (Krawtz *et al.*, 1989).

Cerebral air embolisms are a rare complication, but probably occur as a result of contact between the pulmonary vein and the atmosphere during LPR, in the setting of positive pressure ventilation or a pneumothorax (Golish *et al.*, 1992; Ross *et al.*, 1988). Hyperbaric oxygen therapy is the treatment of choice. Retinal damage can occur when Nd:YAG laser light is accidentally reflected onto eyes not covered by goggles. The eyes of the operator, operating room personnel, and patient should be protected.

With proper patient selection, precautions, and attention to technique, most of these complications are, to a great extent, preventable. Furthermore, the risks of Nd:YAG LPR should always be weighed up against the potential benefits, especially when palliation is the goal of treatment.

Part B: Photodynamic therapy

Apart from its thermal effects, the laser has also been used clinically for its photochemical effect. Photodynamic therapy (PDT) is a novel and exciting treatment modality for microinvasive endobronchial non-small cell lung cancer in patients in whom surgery and radiotherapy are not recommended. PDT is a two-step process requiring the administration of a light-absorbing chemical (photosensitiser) and the delivery of light from a nonthermal laser. The main photosensitizer used initially was a haematoporphyrin derivative as di haematoporphyrin ether (DHE). Currently, a more purified form called porfimer sodium (Photofrin) is usually used. Photofrin is initially administered intravenously at a dose of 2 mg/kg. The patient is then shielded from sunlight via protective clothing and goggles for four to six weeks. Photofrin circulates in the body, is retained in the tumour cells, and clears out of most healthy tissues within six hours, except for the lung, reticuloendothelial tissues (including liver and spleen), and skin. After 48-72 hours, Photofrin is mainly retained by the tumour cells (Dougherty, 1987). The cytotoxic and antitumour property of Photofrin is light- and oxygen-dependent. After 40-50 hours of Photofrin administration, the tumour site is exposed to bronchoscopic illumination with a 630-nm wavelength of laser light. Various kinds of lasers, including argon dye, gold vapour, copper dye, excimer dye, diode, and YAG, with a potassium titanyl phosphate crystal or an optical parametric oscillator, have been used. The most common light source used is the argon pump-dye laser. For endobronchial cancers, the light dose with the argon dye laser is 200 J/cm of tumour length. Cellular disintegration results from radical reactions producing superoxide and hydroxyl radicals, and ischemic necrosis from vascular occlusions, probably due to thromboxane A2 release (Dougherty and Marcus, 1992). This reaction results in tumour necrosis with relative preservation of the normal tissue. The necrotic effect and inflammatory responses of PDT may evolve over several days. A clean-up bronchoscopy two to four days later will be needed to remove necrotic tumour debris as otherwise this may result in respiratory distress (Balchum and Doiron, 1985; McCaughan *et al.*, 1986). If residual tumour is seen during this follow-up bronchoscopy, repeated laser light treatment can be administered. Complications have been minimal, but patients can develop haemoptysis or bronchial fistulas from bronchial tissue necrosis. More common are the photosensitivity skin burns. The rate of this complication can be dramatically reduced by following the instructions to avoid direct sun exposure.

Endobronchial ultrasound (EBUS) has been studied as a selection tool to decide if PDT therapy is the best treatment option (Miyazu *et al.*, 2002). In that study, patients with intracartilaginous spread received PDT and had a good long-term response, while those with extracartilaginous spread were referred to receive other modalities of therapy. PDT can be curative in patients with early stage central airway tumours. McCaughan *et al.* (1997) found that the 5-year disease-related estimated survival of patients with stage 1 treated with PDT is 93%. In another study, PDT was found to be efficacious in the treatment of superficial lung cancer with complete remission rate of 83.2% (Kato *et al.*, 1996). A report from the Mayo Clinic found that at least 22% of patients with early stage squamous cell lung cancer who are candidates for PDT can be spared surgical resection (Cortese *et al.*, 1997). PDT has been also used to palliate central endobronchial obstruction. Moghissi *et al.* (1999) studied 100 patients with advanced inoperable bronchogenic cancer and endobronchial luminal obstruction. After PDT, the mean endoluminal obstruction fell from 85.8% to 17.5% and the mean forced vital capacity and forced expiratory volume in the first second of the measurement improvement was 430 ml and 280 ml, respectively. PDT was compared to Nd:YAG laser in patients with partial or complete tracheobronchial obstruction due to inoperable lung cancer (Diaz-Jimenez *et al.*, 1999). Both were found to have similar effectiveness and safety when it comes to palliation of symptoms.

Also, combined brachytherapy and PDT in patients with extensive endobronchial lung cancer was assessed. Freitag *et al.* (2004) showed that this modality of treatment was safe and had excellent therapeutic efficacy.

PDT has also been used in the treatment of recurrent juvenile laryngotracheobronchial papillomatosis (Kavuru *et al.*, 1990). Abramson *et al.* (1992) treated 33 patients with PDT and found a 50% reduction in the average growth, with three patients being disease free for more than two years. A follow-up report indicated no significant change in response of the papillomas when the light dose (argon pump dye laser) was increased from 50 to 80 J/cm^2 (Abramson *et al.*, 1994).

Part C: Lasers in the early detection of lung cancer

Lung cancer detected early is potentially curable. Screening with routine bronchoscopy is of no use since dysplasia and carcinoma *in situ* lesions are not often visible under white light bronchoscopy (WLB). With the help of the photochemical effect of the laser, the bronchoscope's ability to detect early mucosal lesions has been improved.

Lam *et al*. developed the light-induced fluorescence endoscopy (LIFE) device (Xillix Technology Corp, Richmond, BC, Canada). This is a real-time diagnostic bronchoscopic imaging system that delivers a blue light (442 nm) from a helium-cadmium laser beam into the endobronchial tree (Palcic *et al.*, 1991; Lam *et al.*, 1993). The blue laser light acts as an excitation source that induces differential autofluorescence of the cancerous and dysplastic tissues. Two image-intensifying charged couple device cameras capture this weak, low intensity fluorescence. The computer then processes these signals into a real-time colour pseudo-image. Normal mucosa is arbitrarily assigned a green colour. A red or brownish-red colour suggests dysplastic or cancerous tissues. In a multicentre clinical trial, the relative sensitivity of WLB + LIFE versus WLB alone was 6.3 (0.56 versus 0.09) for intraepithelial neoplastic lesions and 2.71 (0.67 versus 0.25) when invasive carcinomas were also included (Lam *et al.*, 1998). However, the positive and negative predictive values were only 0.33 and 0.89, respectively, and these were not significantly different from WLB. The laser-induced LIFE autofluorescence system is no longer commercially available. Currently, non-laser autofluorescence systems using lights like xenon are in use. The role of these non-laser systems in early lung cancer detection is beyond the scope of this book. Recently, Pentax developed the SAFE-3000 autofluorescence system that uses diode laser light for the excitation of the airway mucosa. In a study of 154 patients, Ikeda *et al.* (2006) found that the SAFE-3000 system has a higher sensitivity (90%) for identifying intraepithelial lesion than WLB (sensitivity of 65%). The impact of autofluorescence bronchoscopy on clinical outcomes, including mortality, still needs further studies.

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MCQ – 55. Lasers in the lower airways

1. Nd:YAG laser the preferred laser for lower airway surgery because
   a. It can be used through the rigid as well as the flexible bronchoscope
   b. It has a good haemostatic property
   c. It has a shallow penetration depth
   d. It produces a collimated beam when delivered through the fibre
   e. All of the above

2. Rigid bronchoscopy is preferred method over flexible bronchoscopy because
   a. It can be carried out under sedation
   b. It provides a better control for laser photoresection
   c. CO_2 laser can be used with a coupler
   d. The beam can be taken much more distally than the flexible bronchoscope
   e. Smoke can be evacuated more efficiently

3. Laser tissue effects are governed by
   a. Power density measured as watts/exposure time
   b. Power density measured as watts/cm^2
   c. Distance between the tip of the fibre and the target
   d. Pulse duration – shorter exposure time causes more charring
   e. Pulse duration – shorter exposure time causes rapid tissue loss

4. A highly vascular tumour should be removed by
   a. Vaporising the base of the tumour
   b. Using a snare and then the laser
   c. Vaporising the surface, layer by layer
   d. Coagulating with the laser and then vaporising layer by layer
   e. Laser should not be used

5. While considering laser photo-resection, the following should be taken in to account
   a. Vascularity of the tumour
   b. Location of the tumour: involvement of lobar or segmental bronchi as against trachea and main bronchi including carina
   c. Duration of life expectancy of the patient
   d. Involvement of the corresponding segment of the pulmonary artery
   e. All of the above

6. The therapeutic outcome of the laser photo-resection is governed by
   a. Inability to visualise distal lumen
   b. The vertical extent of the tumour
   c. The number of walls involved
   d. The duration of lung collapse
   e. All of the above

7. In subglottic and tracheal stenosis, the prognosis for laser management is poor when
   a. The aetiology is iatrogenic as against trauma
   b. When both the glottis and the subglottis are involved
   c. In laryngo-tracheomalacia
   d. In circumscribed lesions more than 1 cm in length
   e. All of the above

8. Following radial incisions for complete subglottic and / or tracheal stenosis
    a. Subsequent dilatations are best undertaken with increasing sizes of bougies
    b. Subsequent frequent dilatations are best undertaken with increasing sizes of rigid bronchoscopes
    c. Subsequent dilatations are best undertaken with gentle manipulations of largest possible rigid bronchoscope which the patient’s airway is able to accommodate
    d. The patency is maintained with T-tube stent and frequent rigid bronchoscopic dilatiatoins
    e. No further manipulations should be carried out in order to avoid trauma to the epithelium.

9. Following laser photo resection
    a. Topical steroids are advocated
    b. Systemic steroids are advocated
    c. Both topical and systemic steroids are advocated
    d. Steroid should not be given for fear of delayed epithelialisation
    e. There is no consensus on the steroid protocol

10. In order to prevent infection of the operative site and subsequent healing with scar formation
    a. Prophylactic antibiotics should be routinely given
    b. Intraoperative parenteral antibiotics should be given
    c. Pre- and postoperative course of antibiotic is advocated
    d. There is no consensus on antibiotic protocol

11. Pre-radiotherapy laser photo-resection of endobronchial tumour generally
    a. Improves outcome of palliative therapy
    b. Has no effect of long term survival
    c. Improves patient’s ability to better tolerate external palliation beam radiation
    d. Is advocated in all indicated cases irrespective of the origin of the malignant tumour (primary or metastatic)
    e. All of the above

12. Intraoperative bleeding
    a. Is a rare complication of treating the endobronchial malignancy with laser photo-resection.
    b. Is a significant complication since most malignant neoplastic tumours are vascular
    c. Is usually anticipated by preoperative study of the relationship of the major thoracic vessels and the traheo-bronchial walls with CT scan or MRI.
    d. The incidence is reduced by understanding and strict adherence to the recommended power setting
    e. Rigid bronchoscope provides a better control in its management.

13. In laser photo-resection, the surgical fire can be avoided
    a. By avoiding concentration of oxygen above 40%
    b. By keeping the balloon near the vocal cord, away from the lesion
    c. By extending the fibre tip beyond the end of the flexible bronchoscope
    d. By removing the fibre and cleaning it regularly
    e. All of the above

Section IX: Lasers in Chronic Tropical Inflammatory Diseases in Otolaryngology

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M. Kameswaran, S. Raghunandhan, W. Jerjes and T. Upile

Chapter 56

Lasers in Chronic Tropical Inflammatory Diseases in Otolaryngology

M. Kameswaran, S. Raghunandhan, W. Jerjes and T. Upile

Introduction

Tropical environment has a unique ecosystem which predisposes to the prevalence of a myriad of diseases affecting various parts of the human body. In otorhinolaryngology, the hot and humid climate of the tropics provides a fertile ground for various infections and vectors, propagated by cultural food habits and life style.

The introduction of lasers in the clinical practice in the past few decades has provided the surgeon with an additional tool. This chapter provides an overview of some of these conditions characteristic of the tropical regions and describes the role of lasers in their management. It is divided in three parts. Part A covers chronic inflammatory conditions. Part B is allocated to oral sub-mucous fibrosis (OSMF). OSMF is a markedly debilitating condition. It is endemically prevalent in the Indian subcontinent, and, in some cases (from 1.9 to10%), progresses to malignancy – hence its separate coverage in Part B. Part C covers the use of lasers in tropical diseases in some detail, since its introduction in this entity is fairly recent.

As in other laryngeal conditions, the CO_2 laser remains a preferred wavelength for topical diseases affecting the larynx whereas KTP-532 or the diode laser is preferred for nasal conditions, due to their fibre-transmissibility.

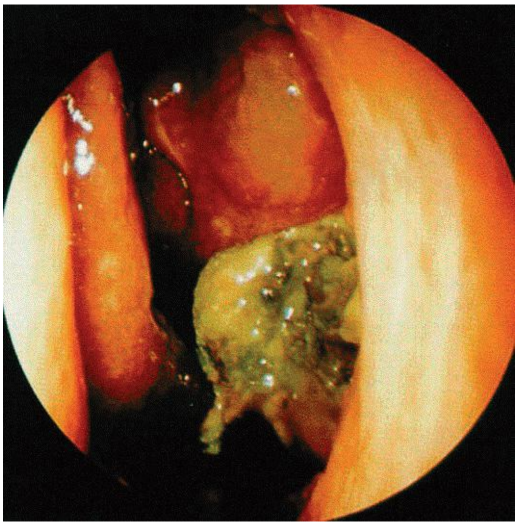

Fig. 1. Fungal granuloma in middle meatus of nose. Note the typical fungal lesions surrounding the granuloma.

Part A. Chronic inflammatory conditions in the tropics

M. Kameswaran, S. Raghunandhan

1. Mycotic lesions of the nose

Hot and humid tropical environment provides an ideal biosphere for fungal spores to thrive and spread in the nose and paranasal sinuses. Nearly 10% of chronic rhinosinusitis diagnosed in the Indian subcontinent has a fungal aetiology. The fungal invasion

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of sinuses may be isolated or disseminated into all the sinuses.

In immuno-compromised individuals, the fungal invasion is virulent whereas in immuno-competent persons it is characterised by allergic fungal rhinosinusitis.

Nasal endoscopy shows a typical fungal granuloma, serpenginous allergic mucin, pale polypoidal nasal mucosa with polyps occluding the osteo-meatal units (Fig. 1). The non-invasive allergic fungal polyps in the nose and sinuses can be best treated with endoscopic sinus surgery using fibre-transmissible KTP-532 or a diode laser, with minimal bleeding and morbidity (Chapters 24 and 25). Laser is also used to undertake debridement of fungal debris with minimal blood loss.

2. Leprosy of the nose

Leprosy presents as a chronic granulomatous lesion caused by *Mycobacterium leprae* which has a distinct predilection for skin, peripheral nerves and mucous membrane of the upper aero-digestive tract. Nasal leprosy primarily involves the anterior end of the inferior turbinate as a nodulo-granular lesion. Laser management is limited to the excision of nodular lesions.

3. Filariasis

Filariasis is a protozoal infection affecting the lymphatic system of the body. The microfilariae transmitted by insect vectors disseminate from the inoculated sites via the subcutaneous lymphatics with retention of lymph. Clinically, there is persistent non-pitting oedema of the affected structures, much like lymphoedema following radiotherapy. In the head-and-neck region, the loose areolar supraglottic mucosa, with its rich lymphatic circulation, is particularly prone to develop obstructive symptoms. The solid lymphatic oedema leads to stridor, morbid sleep apnoea and, in some cases, life-threatening acute airway obstruction.

A video laryngoscopy shows a classical picture of pale oedematous supraglottis with distorted epiglottis and ventricular folds, covering the true vocal folds, which may not be visible (Fig. 2). The base of the tongue, the pharyngo-epiglottic folds and arytenoids mounds may also be involved by the lymphoedema, contributing to dyspnoea.

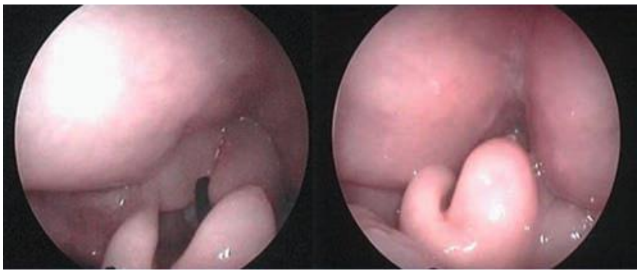

Fig. 2. Laryngeal filariasis causing supraglottic oedema.

The CO_2 laser is particularly suited to ablate the obstructing lesions without any collateral damage to the surrounding structures. The functional integrity is thus fully preserved. Concomitant aggressive anti-filarial therapy helps to cure the disease without any morbid sequelae. An initial post-operative CPAP support is useful in some patients.

4. Rhinosporidiosis

Rhinosporidiosis is a tropical fungal infection caused by *Rhinosporidium seeberi*. Although it was first described in Buenos Aires by Seeber (1900), over 95% of cases are reported from India and Sri Lanka. It tends to affect younger males and is endemic in many regions of the Indian subcontinent.

This disease is characterised by the formation of chronic multiple vascular polypoidal granulomatous lesions. The common sites are the nose, nasopharynx, oropharynx, larynx, and trachea. However, in some cases, the lesions are widespread, involving the nasolacrimal duct, conjunctiva, and tarsal plate. Cutaneous and disseminated type shows multiple nodules involving the sub-cutaneous plane all over the body, aptly called 'malignant rhinosporidiosis' (Figs. 3, 4, 5).

Rajamanickam *et al.* (2002) studied DNA using the Random Primer Analysis of molecular DNA and confirmed stagnant water in ponds as a source of transmission for rhinosporidiosis. DNA samples from infected tissues and from free living spores in infected ponds matched and showed similar patterns.

The granulomata are traditionally managed by wide endonasal excision with diathermy and cautery to the base. However, recurrence is a common feature with this treatment modality. These conventional surgical procedures usually involve substantial blood transfusions and prolonged hospitalisation as the bleeding during surgery is profuse and can be life threatening.

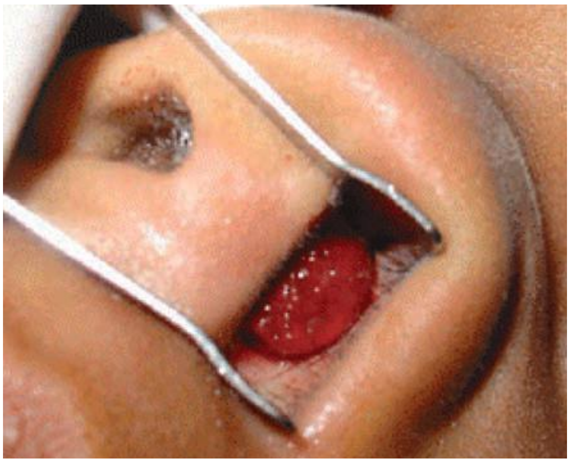

Fig. 3. Rhinosporidial mass seen on anterior rhinoscopy.

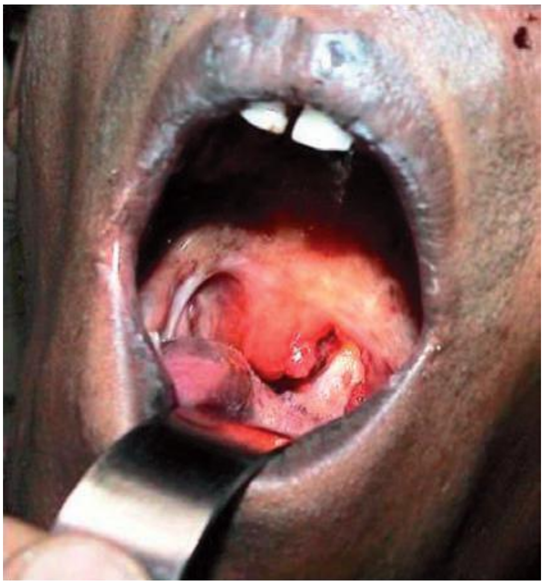

Fig. 4. Oropharyngeal rhinosporidiosis.

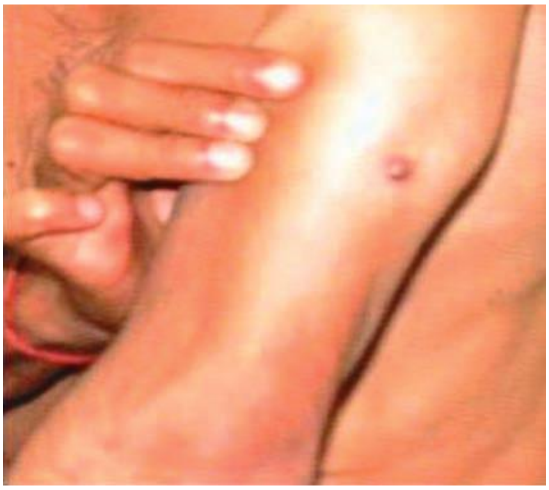

Fig. 5. Cutaneous rhinosporidiosis.

Laser has numerous advantages over the conventional electro-cautery for rhinosporidiosis.

- The KTP-532 laser has excellent cutting and coagulating properties and the laser energy is delivered via the optical fibre through an endoscopic portal. The fibre is easily manoeuvred to 'difficult-to-reach' areas.
- The amount of energy and therefore the depth and the lateral spread of the thermal destruction can be precisely controlled. The delicate mucosa not involved in the disease process is thus spared from damage and scarring.
- KTP-532 wavelength is selectively absorbed by haemoglobin. The haemostatic property of the KTP laser is thus useful in minimising blood loss during surgery.
- The most effective way to use the laser is to fulgurate and vaporise the lesions in near-contact mode. This 'no-touch' technique minimises any likelihood of iatrogenic implantation.

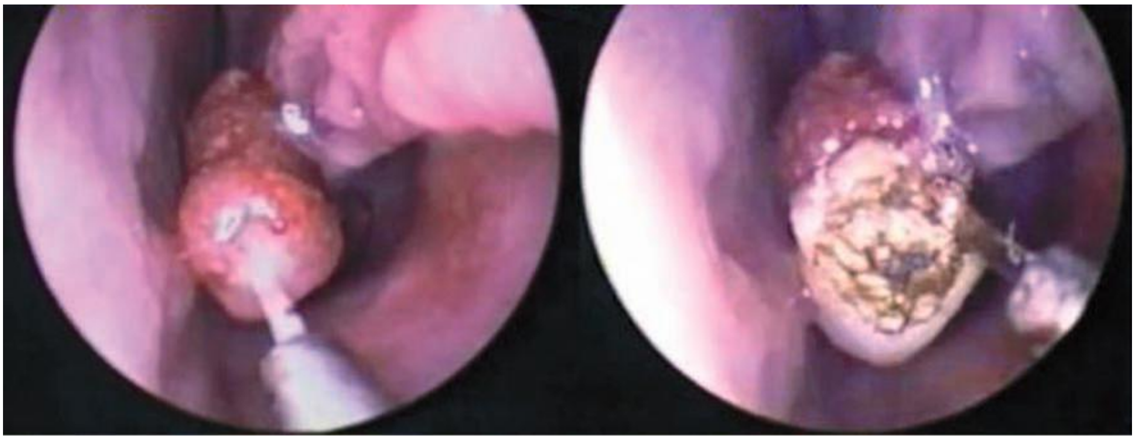

Fig. 6. Endoscopic vaporisation of rhinosporidiosis with KTP-532 laser (note lack of bleeding providing a clear view of the lesion)

- The most striking benefit of the laser is *clear visibility* of the lesion since lack of intraoperative bleeding ensures that the target is not obscured from view by blood (Fig. 6). Transfusions can be avoided in most cases treated with KTP-532 laser.

Trachea-bronchial lesions can be treated using flexible or rigid bronchoscopes without encountering troublesome bleeding. The KTP laser is safe when used in the lower airway while the patient is given inhalational anaesthesia via a ventilating bronchoscope or when ventilated by an intermittent apnoeic technique using jet ventilation (Fig. 7).

In a double-blind study, Kameswaran *et al.* (2002) found dramatic reduction in the need for blood transfusion in most cases. The recurrence rate was low and was thought to be due to additional foci of infection or due to micro-spread along the lymphatics from the sites of lesion.

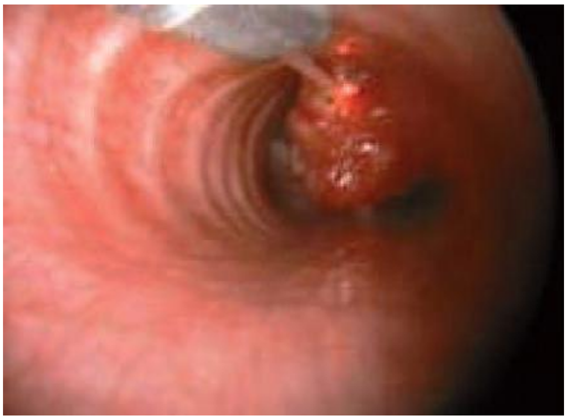

Fig. 7. KTP Laser vaporisation of tracheal rhinosporidiosis

5. Primary tuberculosis

Otolaryngological practice in the tropical environment commonly involves management of primary nasal tuberculosis (TB), tubercular laryngitis and tubercular otitis media. Its impact is greater in the developing countries of the tropical world, where this micro-organism thrives at its best. However, its resurgence in immuno-compromised conditions such as HIV, in chronic steroid therapy and in chemotherapy for malignancy, the clinical presentations of tubercular infection have involved every system in the body. Both pulmonary and extra-pulmonary TB, caused by Mycobacterium tuberculosis has emerged as a major health issue the world over during the past two decades.

Nasal TB is an entity rarely reported in Western literature, but often occurs in the middle-aged female population of the tropical countries. On rhinoscopy, the lesion appears as a fleshy, granular pinkish-red, friable, soft-tissue mass often seen attached to the inferior turbinate or the adjoining nasal septum (Fig. 8). Untreated cases show rapid progression of the lesion into the paranasal sinuses with ulceration, epistaxis and perforation of the nasal septum.

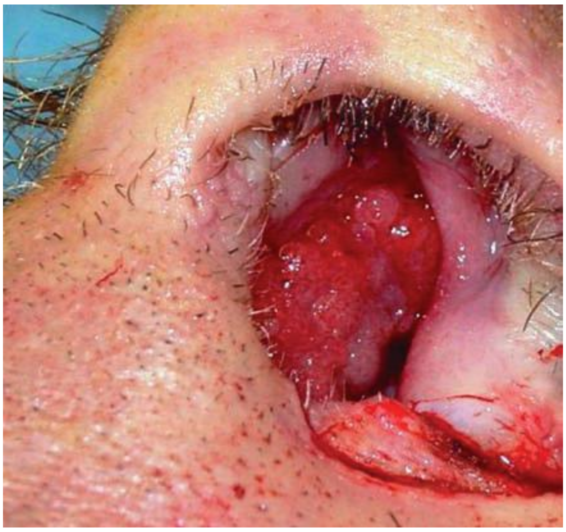

Fig. 8. Tubercular granuloma of the left nasal cavity.

The Authors' rationale in the management of nasal TB is limited to perform endoscopic excision of the granular lesion with KTP/532 laser, relieve the symptoms of nasal obstruction, confirm the diagnosis and involve a TB specialist in the treatment plan for optimal medical therapy and stringent long-term follow up. In our experience, all nasal tubercular lesions respond well with the standard Anti-Tubercular Therapy (ATT) regimen as advocated by the infectious-disease specialists.

6. Lasers in rhinoscleroma

Rhinoscleroma, also known as Mikulicz disease, is a chronic, progressively debilitating, specific, granulomatous, infectious disease affecting the upper respiratory tract. It is a worldwide disease that occurs under all climatic conditions, but most cases are reported from tropical countries in the Middle East, South and Southeast Asia.

Rhinoscleroma is a debilitating disease due to fibrosis and sclerosis. It almost always affects the respiratory tract. The nose is the most common site (95-100%) (Fig. 9). It usually starts in the sub-epithelium of the nasal mucosa, spreading thereafter to other areas, such as the sub-epithelium of the pharynx, which is involved in 50% of cases. Extension to the oral cavity or oropharynx is seen in 18-43% of patients. Other affected sites include the Eustachian tube, maxillary antrum, oral cavity, subglottic larynx, orbit, trachea and bronchi. Females are more frequently affected than males (ratio 13:1).

This disease manifests as three overlapping phases: (1) The catarrhal, atrophic or exudative phase; (2) The nodular, granulomatous or proliferative phase; and (3) The sclerotic, cicatricial or fibrotic phase.

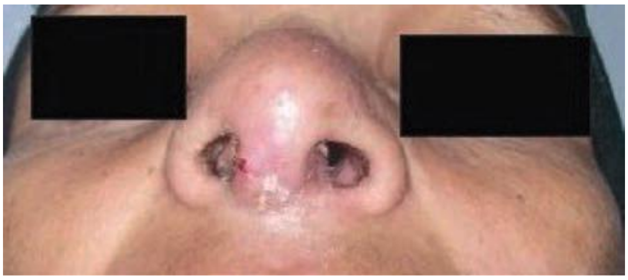

Fig. 9. Rhinoscleroma involving the nasal vestibule.

7. Management

Medical management

Detailed medical management is outside the scope of this chapter. Suffice it to say that a surgical procedure is undertaken only when there is no evidence of residual disease activity in the tissue to be debrided. Premature surgical intervention carries a significant risk of iatrogenic dissemination.

Surgical intervention

CO_2 or KTP/532 laser can be used to precisely excise these lesions in the nose or airway, with minimal blood loss. In advanced cases there is a role for reconstructive plastic surgery of the nose. Pregnant women could be a special group affected with serious airway obstruction by the granulomatous infiltration into the laryngotracheal mucosa, most commonly manifesting as a sub-glottic stricture (Fig. 10). Such trachea-bronchial stenosis can be aptly managed by a staged bronchoscopic KTP/532 or CO_2 laser excision and dilatation (Chapters 16 and 55). Even after comprehensive medical and laser therapy, some patients may remain with sequelae, such as hoarseness of voice due to fibrosis of the vocal folds and dyspnoea due to cicatrisation and re-stenosis of the larynx or trachea. The treating physician must counsel the patient candidly and in detail about the scope of surgical intervention before accepting to treat rhinoscleroma.

Part B. Oral submucous fibrosis

M. Kameswaran, S. Raghunandhan, W. Jerjes and T. Upile

8. Introduction

Oral submucous fibrosis (OSMF) is a slowly progressive, chronic, inflammatory disease of the oral cavity and oropharynx. In advanced cases, the lesions involve the faucial pillars, buccal mucosa.

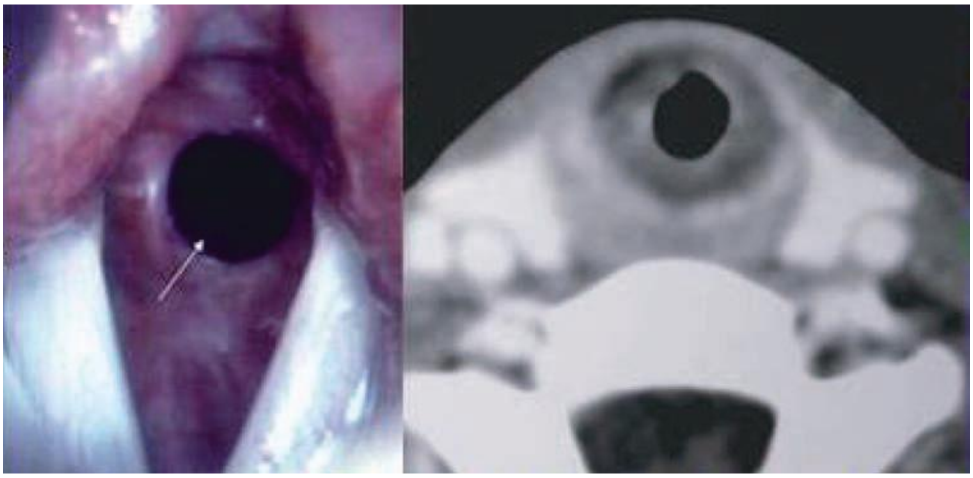

Fig. 10. Scleroma of subglottic larynx.

rima oris, retro-molar trigone and tongue borders which are denuded of papillae.

The condition is characterised by fibro-elastic transformation of the juxta-epithelial connective tissue layers which are rich in collagen. The presence of palpable rigid fibrous bands with overlying blanched mucosa clinches the diagnosis of OSMF. The submucosal rigidity is of varying intensity and leads to trismus and difficulty in effective mastication (Hamner *et al.*, 1974; Canniff *et al.*, 1986) (Figs. 11 and 12).

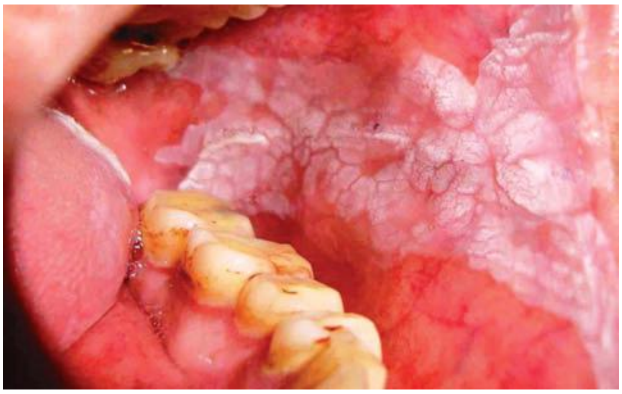

Fig. 11. Oral submucous fibrosis involving the gingivo-buccal mucosa.

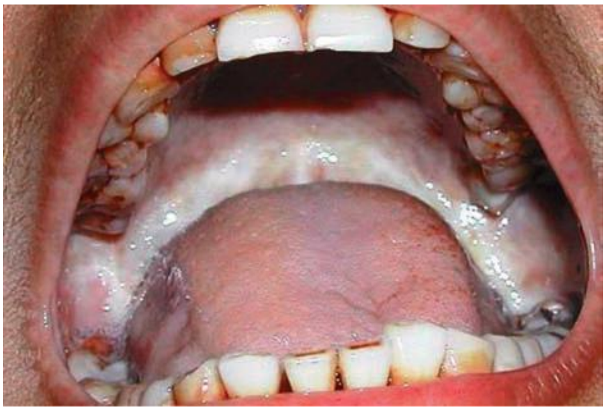

Fig. 12. Extensive palatal submucous fibrosis causing trismus.

9. Demography

OSMF is common in Asian communities and specifically in the communities from the Indian subcontinent and the Pacific islands. The incidence in the Indian subcontinent can reach up to 2.3% for males and 4.5% for females (Hamner *et al.*, 1974; Pillai *et al.*, 1992). Although in the Western countries the condition is rarely encountered in the indigenous population, the immigrant population from the Indian subcontinent does show preponderance. The age range is wide and the female population shows a slightly higher incidence.

10. Aetiology

OSMF was first described by Joshi (1952), who identified the common irritants which predispose to the occurrence of OSMF as betel quid, areca nut, chilli peppers and chewable tobacco, which are traditionally used in some parts of Central, South and South-East Asia. Interestingly, the incidence of OSMF is much lower amongst the Mexicans and the South Americans in spite of significant chilli-pepper consumption (Hamner *et al.*, 1974; Haque *et al.*, 1997).

Auto-immunity and a genetic predisposition have also been implicated in the development of OSMF (Haque *et al.*, 1997; Chang *et al.*, 2002; Jacob *et al.*, 2004). There is often a hereditary predisposition along with a prolonged exposure to a local mucosal irritant.

The process is augmented in patients with nutritional deficiencies (vitamin-B-complex deficiency, iron deficiency anaemia and generalised malnutrition) (Haque *et al.*, 1997; Chang *et al.*, 2002; Jacob *et al.*, 2004).

11. Symptoms

In most patients with a long-standing substance abuse, the onset of OSMF is insidious and sub-clinical. As the pathological changes progress, various symptoms appear. In advanced cases, the condition is debilitating, with a high morbidity.

OSMF is divided into three stages depending on the severity of changes in the oral mucosa and its surrounding tissue at presentation. In stage 1, the patient usually consults a physician with complaints of oral pain, burning sensation, trismus and impaired oral movements.

With continuing substance abuse, stage 1 soon progresses to stage 2, with more symptoms: change in gustatory sensation, increased salivation and xerostomia.

Stage 3 advances to dysphagia (oesophageal involvement), hearing loss (Eustachian-tube involvement) and nasal tonality to the voice (rhinolalia).

The most serious complication of this disorder is the development of oral carcinoma; the incidence varies from 1.9 to10% depending on the age and number of years of exposure to the aetiological factors.

12. Diagnosis

Laboratory investigations are non-specific but may show reduced haemoglobin, iron, protein and vitamin B-complex levels and increased erythrocyte sedimentation rate (Haque *et al.*, 1997; Chang *et al.*, 2002; Jacob *et al.*, 2004; Tu *et al.*, 2006; Tilakaratne *et al.*, 2006). Histopathology is the gold standard for the diagnosis of OSMF (Haque *et al.*, 1997; Chang *et al.*, 2002; Jacob *et al.*, 2004; Nayak *et al.*, 2009; Chaudhary *et al.*, 2011).

13. Management

Medical intervention

Medical intervention has been employed and shows variable degrees of success depending on the severity of the disease and life style changes. Further discussion is beyond the scope of this chapter.

Conventional surgical management

Surgical management is aimed at increasing the opening of the mouth. Traditionally, this has been achieved by severing the fibrous bands with cold instrumentation.

Severity of trismus can interfere with tracheal intubation for general anaesthesia, adequate access the operating site and, more importantly, achieving adequate haemostasis of the operating site, the access to which is severely limited due to trismus.

In advanced cases of trismus, sufficient mouth opening can only be achieved by complete release of all fibrotic tissue, along with coronoidectomy or temporal muscle myotomy. Reconstruction of the resultant defect is often problematic and various methods have been described including split skin grafts, buccal fat pad grafts, tongue flaps, naso-labial flaps or micro-vascular radial forearm free flaps.

However skilfully these procedures are carried out, there are inherent issues. They are associated with a high degree of morbidity of the patients. Malignant transformation, should one occur, remains hidden due to a successful repair with a flap reconstruction. If a flap has been used for reconstruction in the management of OSMF initially, the availability of further flaps is sparse when subsequently a malignant transformation is excised.

Excision with electro-cautery does offer a relatively bloodless field. However, deep thermal spread cannot be controlled accurately and its repair results in more fibrosis, thus negating the beneficial effects.

Laser surgical management

Literature review

A study by Nayak *et al.* (2009) assessed the role of KTP-532 laser in management of oral submucous fibrosis. Nine patients underwent a release procedure using KTP-532 laser. Pre- and postoperative mouth opening was compared using the Wilcoxon signed rank test, and a significant difference was observed ($p < 0.01$). Follow up over an average period of 12 months showed encouraging results. These preliminary results indicated that adequate release of OSMF can be achieved by using a KTP-532 laser release procedure, with minimal morbidity and satisfactory results and should encourage more widespread use of this modality in the management of OSMF.

Another study prospectively examined the role of diode laser in managing eight patients with this condition (Talsania, 2009). Satisfactory results were achieved and the authors concluded that the diode laser is a less expensive alternative in group III and group IV-A cases in whom bilateral temporalis myotomy and coronoidectomy are considered to be the only option. This technique has less morbidity and is suitable for patients as it requires less hospital stay and less follow up as compared to other surgical methods.

In a recent case study (Chaudhary *et al.*, 2011), an 18-year-old male with OSMF was treated with ErCr:YSGG laser. Fibrotic bands in the region of pterygo-mandibular raphe, and faucial pillars were identified by gentle palpation, and under local anaesthesia, a release was done. Mouth opening increased to 25 mm on first post-operative day and continued to improve gradually to 40 mm within the next 15 days. A follow up for six months showed no relapse and the patient was free from trismus.

In the authors' hands, the laser excision of fibrotic bands by 'S-Plasty' and adjunctive therapy with intra-lesional steroids and anti-oxidants has shown excellent results and has major advantages over other conventional surgical procedures.

The KTP-532 laser offers several major advantages over the conventional surgical methods:

- It is possible to carry out precise excision since bleeding is well controlled. An optimum amount of energy limits its deep spread and thermal damage. This leads to healing with minimum fibrosis.
- Its fibre optic delivery takes the energy to confined sites with poor access due to trismus.
- The laser procedure is performed as day-care under local or general anaesthesia and is thus cost-effective.
- The laser energy is non-ionising radiation and thus it has no cumulative effect or dosage limitation. Therefore, the procedure can be repeated as often and as frequently as necessary.

Laser technique

The fibrotic bands are meticulously palpated especially over the pterygo-mandibular region and the faucial pillars in order to assess the severity, induration and the thickness. An accurate pre-operative assessment helps the operator to use *optimum* energy and limit the collateral and deeper thermal damage. Minimal tissue damage allows the raw area to epithelialise spontaneously without any surface grafting. Leaving the raw area without grafting also helps in periodic examination of the wound. It has a dual beneficial role: any residual OSFM can be identified for future management and, more importantly, suspicious but histologically negative areas can be monitored (Mehrotra *et al*., 2009; Kothari *et al*., 2012; Bande *et al*., 2012) (Figs. 13 and 14).

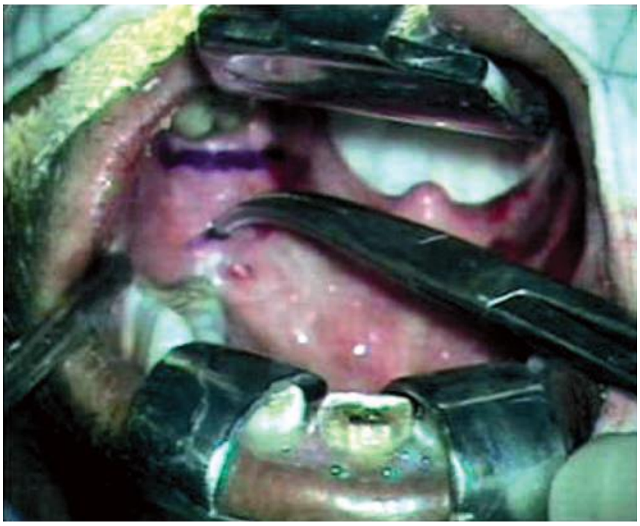

Fig. 13. Z-plasty incision marked for trismus release in palatal SMF.

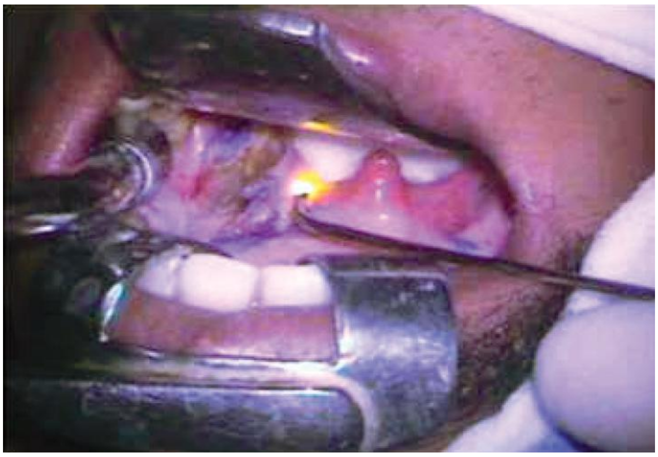

Fig. 14. KTP-532 Laser assisted Z-plasty for palatal submucous fibrosis.

14. Follow up

Patients need to be followed up on a long-term basis to assess recurrence of the trismus and response to treatment. The affected areas are easily visible for inspection and hence any malignant change can be detected at the earliest.

15. Conclusion: Oral submucous fibrosis

With the introduction of lasers, head-and-neck surgeons are provided with a new modality for treating OSMF, the KTP-532, diode and ErCr:YSGG lasers have been effectively used on oral soft tissue without significant collateral thermal damage (Nayak *et al*., 2009; Chaudhary *et al*., 2011; Jerjes *et al*., 2012). Perhaps regimens associated with laser ablation and release, augmented with intra-lesional steroid depot and micro-nutritional supplementation will be the way forward.

Established OSMF is not reversible and remains recalcitrant to treatment. The treatment aims at achieving a long-term symptomatic relief and the introduction of lasers represents an addition to instrumentation rather than providing cure. Adjunctive therapy in the form of jaw-stretching exercises, antioxidants and local intra-lesional steroid or Hyalase injections after laser excision help prevent the recurrence of trismus.

Patient education is pivotal to arrest its progression and a hope to a small but significant number of patients, who are otherwise destined to malignant transformation (Table 1). Oral rehabilitation and life-style modifications continue to remain a corner stone for sustained improvement of this debilitating condition. Therapy to encourage abstinence from chewing the irritant and antioxidant delays progression of the disease and, more importantly, mitigates potential malignant change. Detection of transformation to oral pre-malignant condition and frank malignancy requires a long follow up with compliance to life-style changes.

The categorisation of OSMF as a pre-cancerous lesion has, in recent times, created significant public awareness leading to an increasing abstinence of tobacco and betel quid. The Indian government is playing its role by taking stringent steps to ban commercially available tobacco and betel quid formulations.

Table 1. Patient education with regard to oral submucous fibrosis**.**

Patient education:
➢ Discontinue the habit of chewing betal quid
➢ Eliminate tobacco from the quid product to reduce the risk of oral cancer
➢ Eat a complete and healthy diet (avoid malnutrition)
➢ Maintain proper oral hygiene
➢ Avoid spicy food

Part C. General remarks

M. Kameswaran, S. Raghunandhan

16. Benefit and risk issue

Lasers entered the clinical practice in the early seventies of the last century and have made steady inroads in the management of various clinical entities.

The use of lasers for the management of tropical diseases does not pose any additional risks over and above their routine safety precuations in other areas of clinical practice in otolaryngology (Chapter 3).

While there are a number of advantages the light and laser technology has to offer, on the down side, there are upfront costs of large capital outlay, ongoing maintenance and revenue expenses for consumables. Most of the disease entity described in this chapter is present predominantly in lower social strata who can ill afford the high costs associated with this technology.

The skill level required to use the laser is not extraordinary and can be easily achieved by peer supervision or attending suitable instructional courses.

Socio-economic factors have limited their widespread usage in tropical counties, but with emerging markets in populous countries like India there is an increasing trend to use the hi-tech equipment and, in recent years, a number of centres have acquired surgical lasers.

17. Discussion

Tropical diseases represent an important and often neglected sub-group of disease entity which affects a significant proportion of populations living in the developing countries. These conditions are often associated with substantial morbidity and mortality. While some of the conditions described in this chapter are rare in the developed countries, increasing globalisation, expanding travel industry, emergence of immunodeficiency diseases such as human immunodeficiency virus (HIV) and chemotherapy for malignancy may change the demography in the future. It is advisable for all otolaryngologists to have a practical and working knowledge of the existence of such tropical diseases, with adequate awareness of pathophysiology, clinical presentations, natural history and appropriate management protocols.

Lasers have eased the stress while operating on tropical conditions and have largely simplified the surgical management due to their precision and haemostatic property. The need for complicated procedures to remove such lesions has been obviated.

Morphological and functional recovery following laser surgery is superior when compared with conventional cold-instrumentation surgery and electrocautery. Although epithelial regeneration and wound re-epithelialisation are delayed following laser usage, there are no detrimental effects on the outcome. The advantages of this approach include minimal damage to adjacent tissue, delayed acute inflammatory reaction and reduced myofibroblast activity, leading to reduced wound contraction and scarring. Reduction of collagen in the post-operative phase maintains soft tissue pliability. The coagulum provides an excellent barrier to infection and the laser-treated area can be left exposed to granulate, thus obviating any need for skin grafting or wound dressing (Jerjes *et al.*, 2012).

As in other disease entities, judicious case selection, surgical wisdom and expertise in handling the laser and provision of adequate laser safety precautions for all personnel in operating rooms are a prelude to running a successful laser unit. Surgery for tropical lesions provides an ideal learning experience for training with lasers in the otolaryngological practice.

Over the past few decades, the use of lasers among head-and-neck surgeons has grown dramatically. Their evolution within the specialty not only has broadened current surgical options for treatment, but also contributed to a variety of new procedures that are now commonplace in the head-and-neck management of specific disorders (Jerjes *et al.*, 2012).

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MCQ – 56. Lasers in Chronic Tropical Inflammatory Diseases in Otolaryngology

1. Fungal rhinosinusitis
    a. Is an acute disease with propensity to chronicity
    b. Is characterised by episodic symptoms
    c. Is characterised by chronic inflammation of the nasal and/or sinus mucosa
    d. Can cause symptoms similar to allergic rhinitis
    e. Is a granulomatous disease

2. Its typical appearance consist of
    a. Allergic pale polypoid mucosa with polyp
    b. A granuloma
    c. Purulent discharge
    d. Bleeding
    e. All of the above

3. Lasers
    a. Are used to undertake FESS in for fungal rhinosinusitis.
    b. Are useful for removal of polypi of fungal origin
    c. Debridement of fungal debris with minimal blood loss.
    d. Are adjuvant to anti-fungal treatment
    e. All of the above

4. Nasal leptrosy
    a. Causes chronic purulent rhinosinusotis
    b. Causes allergic polyposis
    c. Primarily involves the anterior end of inferior turbinate as a nodulo-granular lesion.
    d. Laser management is limited to the excision of nodular lesions.
    e. Laser is used for FESS in nasal leprosy

5. Filariasis
    a. Is a protozoal infection affecting the lymphatic system of the body
    b. Is a neurological disease
    c. Results in immunosuppression
    d. In the Head and Neck region, the solid lymphatic oedema leads to stridor, morbid sleep apnoea and, in some cases, life threatening acute airway obstruction
    e. The CO_2 laser is particularly suited to ablate the obstructing lesions without any collateral damage to the surrounding structures.

Section X: Emerging Trends in Laser Applications

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Section Editor: S. Zeitels

SECTION X-A: Office-based Management of Laser Laryngeal Procedures

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Chapter 57

Office-based procedures – an emerging trend

V. Oswal and J. Thomas

1. Definitions

Since the modality of office-based procedure is an emerging science, it is useful to know a working definition of the various nomenclatures. Literature review shows that there is no one acceptable definition or indeed acronym for the various manipulations that can be undertaken in office-based facility, away from the conventional operating suites. The following text has been extracted from a number of articles available in the public domain on the internet.

1.1. Location of facility and safety

This issue is diverse and governed by factors which are outside the scope of this work. However, a standalone facility, away from a well established institute such as a district hospital, will always require preplanning for emergency transfer of patients, should the need arise. Basic resuscitation equipment and competent personnel in its use are a minimum requirement for the safety of the patient. Offices are classified as Level I, II or III, depending upon the complexity of anaesthesia and surgical procedure performed. Detailed description is beyond the scope of this work. However, following is the brief overview (Guidelines for Office-based surgery: http://www.facs.org/ahp/kyOBSguide12-03.pdf).

1.2. Level I office surgery

- Includes minor surgery performed under topical, surface or local anaesthesia. It does not involve drug-induced alteration of consciousness *other than* minimal preoperative anti-anxiety medication, *e.g.*, five to ten mg of diazepam given orally. It is necessary to appreciate that any consent for the procedure needs to be given by the patients prior to the administration of the anti-anxiety medication.
- A further important distinction has to be made that the level of office surgery is based on the effects of the medication on a particular patient and not on the type or route of medication given, or indeed the type of surgery undertaken.
- Excludes procedures where level of consciousness is altered by medication.

Although Level I surgery is considered a minor procedure, it is expected that any practice performing office-based surgery, regardless of anaesthesia, will have the necessary equipment, protocol, and personnel, competent to handle an emergency situation. A plan for emergency transfer to appropriate medical facility should be in place. The physician ideally should have Advanced Cardiac Life Support Certification.

1.3. Level II office surgery

Level II office surgery includes any procedure which requires administration of minimal or moderate sedation/analgesia making post-operative monitoring necessary. Literature review indicates that all office-based laryngeal procedures have been carried out on *unsedated* patients.

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1.4. Level III office surgery

Level III office surgery requires deep sedation or general anaesthesia and does not relate to the topic covered in this chapter.

2. Introduction

Office-based procedures (OBP) have gained momentum in recent years in a number of specialties. Flexible endoscopes with working channels can be passed via natural passages, or key holes.

In laryngology, working channels can be used for passing biopsy forceps or laser fibre to the operating site.

Laser surgery generates smoke which needs to be removed from the operating site in order to obtain clear view of the target. The opposite nostril is also anaesthetised so that a 14 French Gauge flexible suction catheter is passed in to it and advanced in the oropharynx. The proximal end of the catheter is attached to a smoke evacuator, viral filter (eg. http://www.buffalofilter.com). The filter is routinely used for all laryngeal cases to ensure hazard-free environment.

3. Flexible laryngeal endoscopes

In laryngology, flexible laryngeal endoscopes, passed transnasally, provide access to the laryngeal structures in the office-based setting. The external diameter of the working channel endoscopes are about 1.5 mm larger in diameter than endoscopes without a working channel.

Surgery is carried out with a laser light delivered through flexible fibre passed down the working channel of the endoscope. Tissue ablation with the laser, when performed carefully, is almost bloodless, and thus provides an unobstructed view of the pathology. Using various accessories, the depth of thermal damage is minimised and consequently there is hardly any oedema. Collateral damage is also limited, with preservation of surrounding normal structures and their function.

Newer endoscopes with distal chip camera have resulted in sharp and bright images for precision surgery on the vocal folds. Recently introduced techniques using angiolytic lasers (*e.g.*, pulse dye laser, pulsed KTP laser) selectively induce damage to microvasculature which results in involution of the tissue without excision (Franco *et al.*, 2003; Clyne *et al.*, 2005; Zeitels *et al.*, 2006b).

Unlike direct laryngoscopy, there is no possibility of dental injury or bruising or oedema of the tongue.

3.1. Distal chip technology

The endoscopes with distal chip camera technology provide superior imaging. In conventional flexible scopes, the optical fibres carry images from the tip to the eyepiece to the camera head which contains charged coupled devices (CCD). In 'distal chip' technology, CCD chip is placed at the tip of the endoscope, where it automatically focuses and controls the brightness of the image. The result is a superior image which is sharper, brighter and comparable to that obtained with a rigid endoscope. The need for a separate camera head is also eliminated. Distal Chip endoscopes may have a larger diameter than corresponding fibre-optic scopes, but provide a higher resolution view. The external diameter of the distal chip working channel endoscopes is about 5.0 mm (Olympus ENF-VT2 is 4.9 mm Outer Diameter (OD), Pentax VNL-1570STK is also 4.9 mm OD), and offer a 2.0 mm working channel which is used for air-insufflation, suction, introduction of small flexible forceps, and laser fibres. It is possible to pass it transnasally in most patients after adequate decongestion and anaesthesia. Distal chip endoscopes without a working channel are smaller diameter (Olympus ENF-VQ is 3.6 mm OD, Pentax VNL-1170K is 4.1 mm OD). Generally speaking, fibreoptic endoscopes are available in smaller diameters with correspondingly more limited views, but chip endoscopes are shrinking in size and increasing in definition annually.

4. Anaesthesia for office-based laryngeal surgery

Office-based endoscopic laryngeal surgery is much less invasive than the one carried out in the operating theatre, since it is undertaken under topical anaesthesia *without* conscious sedation (Mathison *et al.*, 2009). There is a complete lack of the usual postoperative morbidity that follows direct laryngoscopy under general anaesthesia. The postoperative recovery period is not necessary. Swallowing is unaffected. Therefore, the patient can be discharged within a short time after the procedure. It is quite possible that he or she could return to work, or undertake a long journey home.

4.1. *Topical anaesthesia*

The term topical anaesthesia covers administration of an agent to produce a transient and reversible loss of sensation in a defined area of the body. It is carried out without supplemental medication, on conscious *unsedated* patient. The dosage is equal to or *less* than the manufacturer's recommendation, adjusted for weight. Topical anaesthesia is administered as surface or infiltration anaesthesia or a combination of the two methods. Surface anaesthesia is administered to the mucosal lining of the airway. The technique includes application of anaesthetic as spray for mucous membrane, or solution for gargling. The effect is short lasting and is limited to the area of contact. Infiltration anaesthesia is given by injection of local anaesthetic into the tissue to be anaesthetised. The detail technique is described in Chapter 58.

4.2. *Superior laryngeal nerve block*

In laryngeal surgery, peripheral nerve block is sometimes used by anaesthetising superior laryngeal nerve. A superior laryngeal nerve block will anaesthetise the supra-glottic structures. The airway is initially anaesthetised by gargling 4% lignocaine (or a glossopharyngeal nerve block, see below) prior to the nerve block. Two to three ml of lignocaine is injected between the greater cornu of the hyoid bone and the thyroid cartilage.

4.3. *The glossopharyngeal nerve block*

The glossopharyngeal nerves may be blocked by five ml of 1% lignocaine injected into the area where the base of the tongue touches the palatoglossal fold. The needle must be aspirated to avoid intravascular injection. Gargling with lignocaine followed by a spray of 10% lignocaine is equally effective.

4.4. *A trans-tracheal injection*

Three ml of 2% lignocaine is injected with a 23-gauge needle though the cricothyroid membrane. It anaesthetises the trachea. The needle must be quickly withdrawn since most patients will experience a server bout of cough.

A detailed description of the various techniques for laryngeal office-based surgery is covered in Chapter 58.

5. General contra-indications and unsuitability

Generally, the following conditions are unsuitable for office-based procedures:

- Control of acute bleeding;
- Procedures anticipated to carry a potential risk of bleeding and airway compromise;
- Acute conditions classed as emergencies;
- Stent placement;
- Patients in cardiac failure or have advance COPD (ASA (American Society of Anaesthesiologists) class IV);
- Patients with angina, moderate COPD (ASA class III): These patients require a careful appraisal of their fitness for office-based procedure.

ASA score is a simple and widely used measure of patient health status. It is predictive of post-operative complications that necessitate increased resource consumption, usually unavailable in the office-based setting.

6. Haemodynamic monitoring

Yung and Courey (2010) studied heart rate and blood pressure changes retrospectively in charts of 31 consecutive patients undergoing unsedated laryngeal surgery in office-based location. During the procedure, 9/31 patients had tachycardia (29%) and 7/31 had severe hypertension (23%). The mean change in heart rate was 14.6 beats/min ($P < .0001$). One procedure was terminated prematurely due to alarming rise in both systolic and diastolic blood pressure readings. There was no correlation between changes in systolic or diastolic readings and patient's age. They conclude that significant changes occur in the haemodynamic status of patients undergoing laryngeal procedure in office-based location and advocate adequate monitoring.

7. Fibre-transmissible laser technology

CO_2 laser has remained a workhorse laser in otolaryngology for nearly forty years. However, this very useful laser cannot be delivered through an optical fibre and its energy is available only in the line of sight. There are two hollow flexible waveguides currently being marketed, 'omniguide' and 'FiberLase' (Chapter 59). CO_2 laser is a cutting laser. It is maximally absorbed by water and ablates the tissue by vaporising it. Excision of tissue is undertaken by vaporising the incision line. On the other hand, pulsed KTP and pulsed dye laser (PDL) energy is selectively absorbed by haemoglobin in the blood, heating and coagulating it. These lasers are called angiolytic lasers (Mouadeb and Belafsky, 2007; Hsiung *et al.*, 2003). Both lasers can be delivered to the target tissue via optical fibre and thus can be used in conjunction with the flexible endoscope. A combination of *angiolytic* pulsed-lasers and distal chip technology has been largely responsible for the expansion of office-based management of laryngeal pathology, fuelled further by cost considerations (Rees *et al.*, 2006; Zeitels *et al.*, 2004; Zeitels *et al.*, 2006a). Detail description of the various issues is in Chapter 60.

8. Office-based procedure

Office-based laryngeal procedures cover diagnostic, therapeutic and monitoring procedures, described in paragraph 11, under flexible endoscopic laryngeal procedures.

9. Office-based surgery (OBS)

Office-based surgery means any surgical or other *invasive* procedure performed on the patient in a location other than a hospital or a diagnostic treatment centre, including free-standing ambulatory surgery centres. The patient stays in the facility for less than 24 hours. The surgery is performed by a practitioner and the patient requires anaesthesia, analgesia, or sedation.

The term minor surgery indicates a procedure safely performed on a patient who has received local or topical anaesthesia, without more than a minimal pre-operative (anti-anxiety) medication. The likelihood of complications requiring hospitalisation is deemed to be remote. Most office-based endoscopic laser laryngeal surgery is considered minor surgery since it is carried out under local anaesthesia.

10. Cost economics of OBS

Hi-tech medicine has never been cheap. Research and development costs are high. Consequently, equipment and instrumentation requires a large capital outlay. The returns are controlled by the ability of individual patient to pay for it, as well as willingness for the insurance company to accept reimbursements. Office-based surgery is cost effective since it does not involve the use of operating room facility and it is not necessary to admit the patient to inpatient facility. Due to economic pressures, it is likely that this trend is set to continue, with more and more laryngeal procedures being performed in less intensive medical settings of the office-based practices (Rees *et al.*, 2007). Reimbursement issues can have negative impact on what otherwise may prove to be an effective and a safe alternative to the patient.

11. The flexible endoscopic laryngeal procedure

The flexible endoscopic laryngeal procedure is performed for the following purposes.

11.1. Diagnostic endoscopy

Flexible endoscopy is usually carried out transnasally to inspect the nasal airway, the postnasal space, the superior surface of the palate, Eustachian openings, pharynx, hypopharynx, pyriform fossae, epiglottis, posterior third of the tongue, vallecula, laryngeal inlet, supraglottis, glottis, subglottis and upper trachea. Transnasal oesophagoscopy (TNE) is also carried out to inspect the mucosa for changes of Barretts oesophagus, etc. (Austin, 2006).

11.2. Therapeutic endoscopy

The advent of 'distal chip' high resolution endoscope and fibre transmissible lasers has resulted in extension of diagnostic procedures to surgical manipulations to treat a variety of conditions affecting the larynx. The term 'office-based flexible endoscopic surgery (OBFES)' seems appropriate for such manipulations. Some authors prefer to add the word laser to the name which thus becomes office-based flexible endoscopic laser surgery (OBFELS). A variety of nomenclature is perhaps a reflection of reimbursement schedules. Biopsies can also be undertaken, from sites ranging from postnasal space down all the way to the trachea and right main bronchus.

11.3. Endoscopy for monitoring reflux

In a dedicated office-based Voice and Swallowing clinic, transnasal endoscopic oesophagoscopy (TNE) under topical anaesthesia is carried out for biopsy, particularly of suspect tissue, to rule out Barretts oesophagus. TNE has not been used for removal of foreign bodies (FB) from oesophagus. However, a blunt FB at the lower end of the oesophagus can be pushed in to the stomach. TNE has been used for placing a wireless pH capsule to monitor reflux as a cause of chronic persistent and intractable cough.

12. Office-based flexible endoscopic surgery (OBFES)

Chapter 60 covers the conditions that can be managed in the office-based settings. These consist of glottic dysplasia, recurrent respiratory papillomatosis, early T1 cancer and so on. Mathison *et al.* (2009) report awake injection laryngoplasty for unilateral cord paralysis and for glottic incompetency due to bowing of cord, described in the next section.

13. Office-based injection laryngoplasty

Mathison *et al.* (2009) compared results of injection thyroplasty (IT) in a series of 141 consecutive patients, carried out in one group as office-based awake procedure, and in another, under general anaesthesia, as asleep procedure. The outcome was measured under two parameters, as voice related quality of life (VRQOL) and as complication rate. They found that the VRQOL was comparable in both groups. The complication rate was slightly higher in awake IT, although most of the complications were minor. Awake IT obviously has advantages of reduced morbidity due to topical anaesthesia.

14. Risk-benefit issues

A number of positive points have already been covered under various headings.

Cross infection by HIV and MRSA is a limiting factor for the number of procedures that can be undertaken, since the scopes must be effectively sterilised between consecutive procedures.

Most optical fibres in routine use are marketed for single use and add significantly to the overall costs. Some fibres are marketed for multiple use. This may in fact mean that they can be cleaved intra-operatively should the tip performance deteriorate due to accumulation of char. After cleaving, they can be used again in the *same* patient and not in another patient.

15. Regulatory issues

Quality assurance of a facility nowadays is an integral part of any health care scenario. Regulatory bodies put out various guidelines to ensure patient safety and equitable surgical outcome. Physicians, health-care workers and providers engaged in office-based surgery should ensure that they are adequately trained and competent. Medical insurance trade may stipulate such a requirement before they will reimburse.

16. Reporting of adverse incidence in office-based procedure

In the USA, while there is a universal mandate for reporting medical incidences and accidents occurring in hospitals and diagnostic and treatment centres including ambulatory surgery centres, there is no such *universal* requirement for office-based procedures, only a few states mandate reporting of adverse events in office-based setting.

17. The Institute for Safety in Office-Based Surgery (ISOBS)

The Institute for Safety in Office-Based Surgery, Inc. (Safety: The Institute for Safety in Office-Based Surgery, Inc. (ISOBS) http://isobsurgery.org) is a national nonprofit organization founded in 2009 in Boston, Massachusetts by physicians to improve the safety of office-based surgery through physician education, research, and patient advocacy. The Institute sponsors educational activities for health-care providers, offers a Certificate of Quality to safe office practices, and confers annual awards to individuals who have advanced the field of office surgery safety. The Institute's leadership includes prominent members of medical community as well as members of public. It is represented by many different medical specialties.

18. Conclusion

Laryngeal procedures in office setting are on the increase due to various factors covered in this chapter. A prospective operator is advised to create a dedicated facility to undertake such procedures rather than undertake it in a make-shift environment. The authors hope that this chapter provides a systematic approach to various issues involved in office-based laser and other laryngeal procedures.

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* Landmark report by leaders in the field.

** First paper that attempts to quantify the potential cost savings of this type of office-based surgery.

MCQ – 57. Office-based procedures – an emerging trend

1. Desirable and minimum requirements for office based surgery are
    a. Basic resuscitation equipment and competent personnel
    b. Proximity of a hospital with inpatient facility
    c. Arrangements for emergency inpatient admission
    d. Dedicated facility fit for the purpose
    e. A competent anaesthetist

2. Office based facility is classified as level I, II and III according to
    a. The type of anaesthetic medication given
    b. The route of anaesthesia administered
    c. The type of surgery undertaken
    d. The complexity of surgery undertaken
    e. The effects of medication on the patient

3. For office-based laryngeal procedures
    a. Surface anaesthesia is administered
    b. Pre-procedure anti-anxiety medication in small dose is administered
    c. For extreme anxiety, sedation is given
    d. Injection anaesthesia is administered
    e. General anaesthesia is given

4. Office-based laryngeal procedure is indicated where
    a. Procedure will last for less than 30 minutes (therapeutic-anaesthetic window)
    b. Where airway is not too extensively compromised
    c. Where bleeding is not anticipated
    d. Where biopsy is indicated
    e. Where injection laryngoplasty is better performed to monitor the effectiveness of the procedure

5. Office-based laryngeal procedure is contra-indicated where
    a. Patient has severe cardio-respiratory condition
    b. Patient is diabetic
    c. Where patient needs to travel long distances to go home
    d. Where patient requires rapid emergency restoration of airway
    e. Patients who have a severe gag reflex

6. The most suitable laser/s for office-based laryngeal surgery is/are
    a. The CO_2 laser delivered via hollow waveguide
    b. The pulsed KTP laser
    c. The pulse dye laser
    d. The diode laser
    e. All of the above

7. In the USA, the office-based facility
    a. Is regulated by each state
    b. Is regulated by a governmental body
    c. Is regulated by a professional organisations (*e.g.* American Society of Anaesthesiologists
    d. Is regulated in only a few states which require reporting of untoward instances
    e. Is regulated by District or Regional Hospitals who will accept patients from office-based facility in case of emergency

8. The increasing trend towards office-based laryngeal procedure is due to
    a. Availability of hi-tech superior distal chip endoscopes
    b. Cost considerations
    c. Less morbidity
    d. Better training of surgeons
    e. Availability of a flexible waveguide for CO_2 laser

Chapter 58

Topical anaesthesia for office based laryngeal interventions

J. Thomas

1. Introduction

Peroral instrumentation of larynx frequently evokes a gag reflex and cough. Nasal endoscopy without decongestion may also evoke a pain response. Effective topical anaesthesia needs to suppress all three parameters: gag reflex, cough and pain.

Therapeutic office-based laser intervention of the laryngeal pathology through the distal chip flexible endoscope calls for a thorough, successful and adequate topical anaesthesia of the larynx. It is possible to achieve this by using one or a combination of the methods described below.

Inadequate anaesthesia is a source of distress and the patient would be apprehensive for follow-up appointments and further therapeutic interventions. A confident, reassuring and deliberate handling of the anaesthetic procedure goes a long way towards a successful therapeutic outcome.

Administration of anaesthesia is carried out via three routes:

- Nasally and perorally with atomiser
- Transcutaneously with injections and
- Regionally, also with injections, to block the sensory component of the superior laryngeal nerve and/or glossopharyngeal nerve.

Anaesthesia in laryngeal intervention in office setting is carried out in steps. Nasal, nasopharyngeal and oro-pharyngeal anaesthesia are required when the flexible scope is passed through one of the nostrils. A working channel renders the scope diameter somewhat larger and thus imparts a stronger pressure or pain sensation.

For a detailed and close examination of the larynx, the mucosal surfaces of the larynx need to be rendered insensitive to gag reflex. The mucosa is made insensitive by spraying the anaesthetic agent with an atomiser. It can also be dripped on to the cords via a cannula or via a working channel.

Base of tongue and epiglottis are contributory to the gag reflex, and will require administration of anaesthetic if they are going to be touched. In the opinion of some surgeons the base of the epiglottis is not amenable to effective spray and requires glossopharyngeal block. Likewise, posterior part of the larynx is also not well anaesthetised with the spray. In the author's experience, such is not the case. Moreover, regional blocks are certainly more difficult and not routinely administered.

Finally, trachea may be anaesthetised separately if the practitioner is unable to obtain a laryngeal gargle (see below).

Regional block of the internal branch of the superior laryngeal nerve can also suppress the pain and the gag reflex. However, it needs to be carried out on both sides and will exclude the neurologic laryngeal examination because the motor innervation to the cricothyroid muscle by the superior laryngeal nerve will also be anaesthetised. Topical anaesthesia does not have this effect.

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2. General anaesthesia

General anaesthesia (GA) is a universally acceptable practice for a variety of surgical procedures in laryngology. However, it is not without drawbacks:

- GA requires an I/V line.
- There can be nausea and vomiting.
- There exists a potential to damage the teeth due to pressure from the rigid scope.
- A numb tongue from the pressure of the rigid laryngoscope may occur in about one out of five patients (20%) and the feeling may persist over a month.
- No functional examination or therapeutic decisions can be performed during GA.

3. Advantages of topical anaesthesia

As against GA, topical anaesthesia (TA) offers some distinct advantages to the patient:

- The patient is awake and is able to maintain his airway unaided.
- For cord augmentation injections, phonation in awake patients optimises the outcome.
- Post-operative nursing care is minimal.
- Can drink or eat soon after the effects of topical anaesthesia wear off.
- Can go home immediately, and also may choose to get back to work.
- Drive car or take a flight soon after the procedure is over.
- TA avoids morbidity which is associated with GA.
- TA avoids tracheostomy for difficult intubation.
- TA is considerably less expensive.

TA is associated with a degree of apprehension, which can be minimised by talking most patients through the procedure. The essence for getting the patients to tolerate the anaesthesia is to let them know of all the sensations they will encounter *before* they encounter them. A physician, who can accurately predict and convey each sensation in a reassuring mannerism before it occurs, engenders the trust of the patient.

4. Drawbacks of topical anaesthesia

A thorough topical anaesthesia requires a degree of cooperation on the part of the patient in respect of:

- The taste of topical anaesthetic.
- The sensation of the inability to swallow for about 30 minutes.
- The initial perception of ‘not being able to breathe’ as the topical anaesthetic takes effect.
- The intervention time, which is limited to about thirty minutes.
- Surgery on a moving target may be sub-optimal and may require repeat procedures.
- There is a small risk of general toxicity if the quantity of drug enters the blood stream.

Complete cooperation is not possible in some apprehensive patients. Five to ten mg of diazepam 30 minutes prior to local anaesthesia helps these patients.

5. Local anaesthetic agents

Commonly used local anaesthetics agents are Lidocaine, Mepivacaine and Bupivacaine. Bupivacaine is a long-acting agent and should be used where prolonged surgical intervention is anticipated. However, most office-based procedures are anticipated to last around 30 minutes and it is common to use Lidocaine routinely. Its action can be prolonged by simultaneous use of epinephrine which constricts blood vessels and prolongs local action due to slow systemic absorption.

6. Technique for topical anaesthesia

6.1. Nasal anaesthesia

6.1.1. Examination of nasal passages

The nasal airway is frequently asymmetrical due to deviated nasal septum, presence of a spur, fullness of turbinate, or a nasal pathology. Select the side which is most patent.

6.1.2. Application of anaesthetic agent

A mixture of 4% topical Lidocaine and decongestant is applied with Mucosal Atomization Device (MAD) (Fig. 1) by squirting in each nostril.

The patient is pre-warned about a bitter taste in the throat, the nozzle is directed towards the floor of the nose and one or two squirts are applied along the floor beneath the inferior turbinate. Similarly, one or two squirts are applied in the direction of the passage between the middle and inferior turbinate.

The gentler curve obtained by going over the inferior turbinate into the nasopharynx can be more

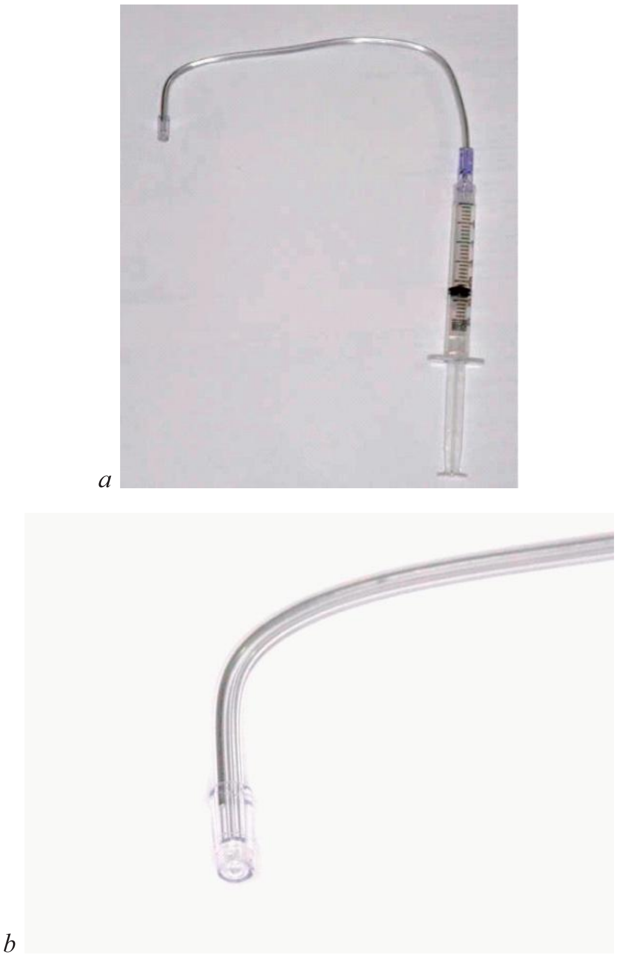

Fig. 1. Mucosal Atomization Device (MAD) (1a: device; 1b: the atomiser tip).

comfortable for the patient and may provide a better view of the soft palate.

6.2. *Transoral application for oropharyngeal anaesthesia*

For diagnostic examination of the larynx a short quick anaesthetic to suppress the gag reflex is all that is necessary. Unlike for nasal anaesthesia, only Lidocaine is used, without the decongestant. With the mucosal atomiser device, a couple of squirts are applied to the posterior tongue and the posterior pharyngeal wall. The nozzle is then advanced further in to the oropharynx and directed towards the base of the tongue and the epiglottis and further couple of squirts are applied if instrumentation to supraglottis or glottis is anticipated (Figs. 2a and 2b).

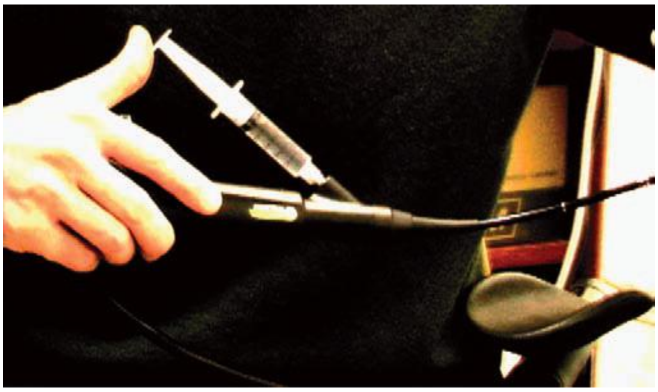

Fig. 2a. Anaesthesia through working channel of the flexible endoscope.

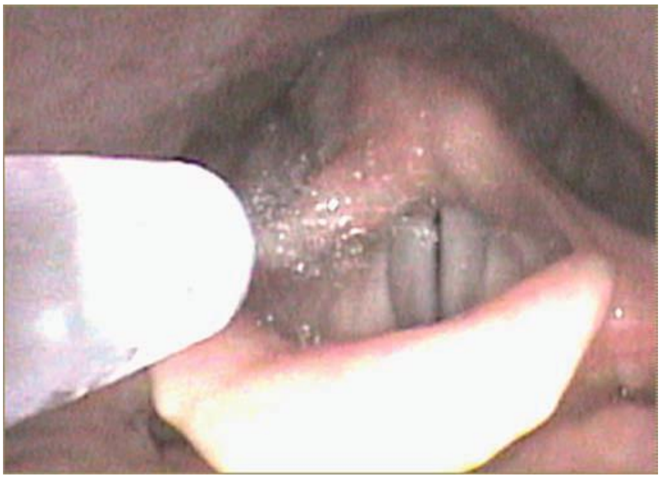

Fig. 2b. MAD spray on the vocal folds.

6.3. *Direct laryngeal application*

For direct laryngeal application, the patient is warned that the spray will result initially in brisk gagging, feeling of lump or choking in the throat, and even a feeling as if they are unable to breath. They may also experience as if they have a swelling in the throat; similar to the feeling of a swollen lip following dental anaesthesia, whereas the lip in fact is not swollen.

The flexible laryngeal applicator may be bent 90°. The nozzle is passed as far back in to the pharynx as possible. The patient is asked to phonate 'eee' and a couple of squirts are applied in quick succession. The patient gags briskly, which helps to spread the anaesthetic. This is the most unpleasant experience for the patient. Lidocaine is sprayed again after 15-30 seconds, while the patient repeats the phonation 'eee'. Thus the anaesthetic is applied to the surface of the vocal cords and disperses around the hypopharynx.

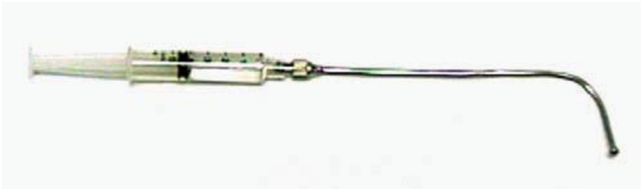

Fig. 3a. Abraham curved cannula.

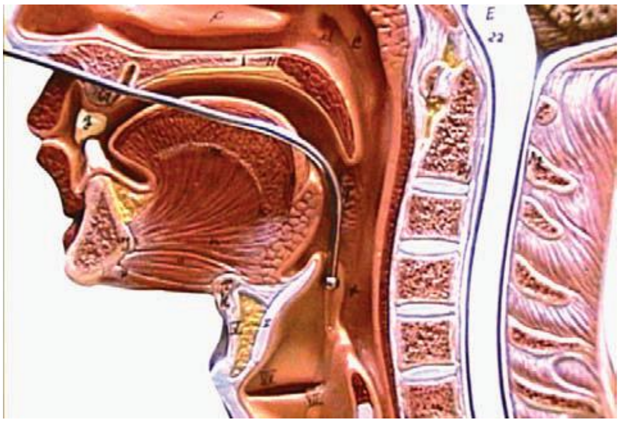

Fig. 3b. The tip of the cannula just posterior to the epiglottis.

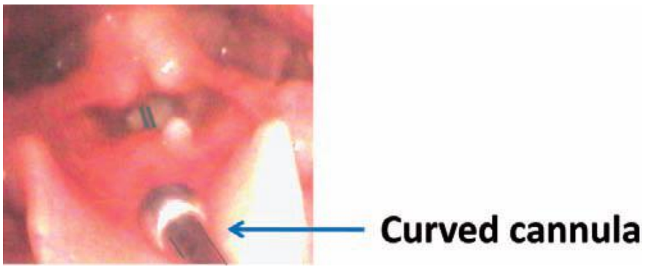

Fig. 3c. Spray with curved cannula.

Abraham curved cannula (Fig. 3) (used in the past to irrigate inferior maxillary antrostomies) can similarly be used for laryngeal anaesthesia.

If this drip cannula is used rather than the atomizer, a gurgling sound is produced as further anaesthetic solution is applied and the patient continues to say ‘eee’, indicating successful anaesthesia of the surface of the vocal folds (Figs. 3a, 3b and 3c).

Typically, a total of four aliquots are used with about one ml of anaesthetic dripped with each application.

6.4. Application of anaesthetic under endoscopic control

The flexible endoscope passed through the anaesthetised nostril provides a direct view of the laryngeal structure during laryngeal anaesthesia. Holding the flexible scope in one hand and the cannula in the other, the surgeon squirts the solution while watching the image on the screen (an assistant holding the scope can ease the procedure). A rigid transoral scope can also be used with a little practice, with the patient holding his own tongue and the surgeon using the scope in one hand and the device in the other.

7. Trans-cricothyroid membrane application of anaesthetic

Some patients have an exceptionally brisk gagging reflex and the common methods of the anaesthetising the larynx described above may not be possible. In such patients, an adequate anaesthesia can be achieved using the trans-cricothyroid membrane route (Fig. 4).

A three-ml syringe with half-inch 25-gauge needle is loaded with 2% Lidocaine and 1:100,000 epinephrine. It may be necessary to use an inch-long needle in patients with obese neck. A small wheal is raised in the skin on the surface over the cricothyroid membrane. The needle is advanced, either horizontally or angled slightly inferiorly. The patient is warned to expect a coughing bout and asked to phonate. Two mls of the anaesthetic is injected quickly in the airway. Patient coughs briskly, experiences the bitter taste of the Lidocaine and as the anaesthetic takes effect, the patient experiences all the sensations described earlier, such as feeling of swelling up, not being able to breathe, etc. A reassuring talk through the process will generally avoid hyperventilation. The patient is asked to ‘hock’ or spit out phlegm that feels stuck in the throat, as once anaesthetised, coughing is generally not effective at expelling pooled secretions.

The trans-cricothyroid membrane method has a merit of speed and simplicity. However, there may be some spotty bleeding in the airway that obscures the laryngeal view transiently.

8. Trans-suprathyroid topical application of anaesthetic

Similar to the trans-cricothyroid membrane approach, a wheal is raised just above the superior thyroid cartilage notch. The needle, after passing the top edge of the thyroid cartilage is directed slightly inferiorly and enters the airway through the base of the epiglottis, just superior to the vocal folds. As the

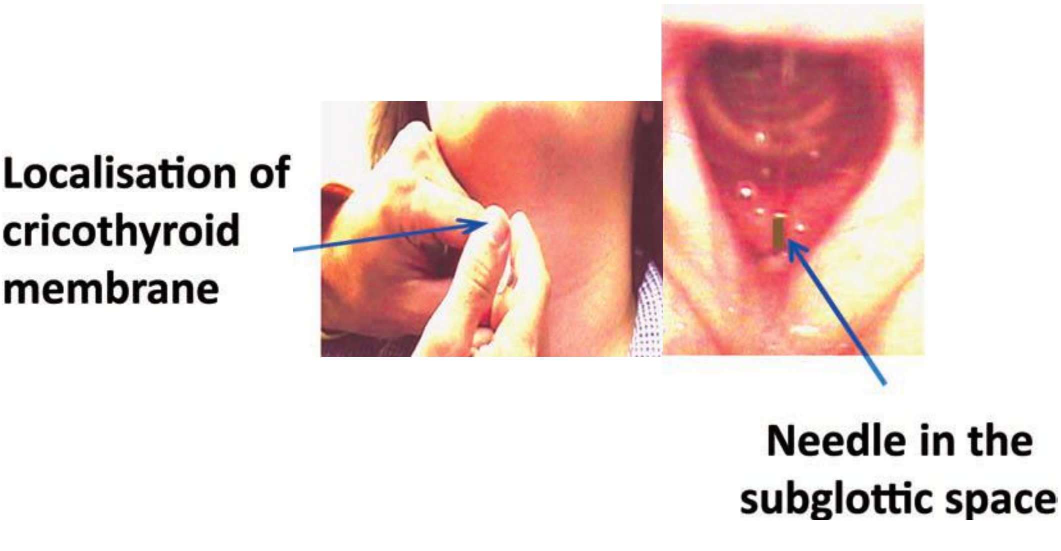
Localisation of cricothyroid membrane
Needle in the subglottic space

Fig. 4. Trans-cricothyroid membrane application of anaesthetic.

patient phonates, the anaesthetic solution is injected. It is atomised on the superior surface of the vocal folds due to the vibrations of the folds during simultaneous phonation. Again, spotty bleeding may occur.

9. Supraglottic anaesthesia

This method is useful for work on the false cord. The injection is administered into the substance of the false vocal folds. A three-ml syringe is filled with two mls Lidocaine with epinephrine. One and a half-inch 25-gauge needle is passed over the superior thyroid notch at an angle of 20° directed inferiorly and 35° laterally. Its passage into the substance of the false vocal fold is monitored with an endoscope. Puncture of the mucosa should be avoided since it will result in bleeding. As the anaesthetic agent is pushed in, the false vocal fold mucosa expands and is blanched, as seen on the monitor.

10. Application via the working channel of the laryngoscope

Following nasal and oropharyngeal anaesthesia, an endoscope with a working channel is positioned over the epiglottis. About one ml of the anaesthetic mixture is dripped onto the dorsal epiglottis via the working channel of the flexible distal chip laryngoscope. In a few moments the endoscope is advanced toward the superior surface of the vocal folds. While the patient phonates, additional aliquots of one ml are dripped onto the vocal folds. Enough time is allowed between the aliquots for coughing or gagging to cease and allowing the anaesthetic to take effect. The subsequent aliquots, dripped as the patient phonates, generate a laryngeal gargle.

On the face of it, the anaesthesia dripped via the working channel seems an easier option. However, the larger size of the scope may cause some pressure in a patient with a smaller nasal passage. An additional and time-consuming cleaning and sterilisation of the working channel are further factors that make this method cumbersome.

11. Superior laryngeal nerve block

The superior laryngeal nerve has two components, a sensory component is the internal branch, which enters the larynx through thyrohyoid membrane and supplies the supraglottic mucosa. The external branch is a motor component, which supplies the cricothyroid muscle.

The regional anaesthesia provided by superior laryngeal nerve block is not routinely undertaken in the author's hands, as the anaesthetic routes described above have always been sufficient to obtain adequate working anaesthesia. Sulica and Blitser (2000) describe the steps as follows:

- The thyrohyoid space is palpated and a point between the hyoid bone and the superior border of the thyroid cartilage is located.
- Halfway between the midline and the superior

cornu of the thyroid cartilage a 27-gauge needle is inserted and advanced until a spring-like feel is obtained, indicating the location of the thyrohyoid membrane.
- The plunger is drawn back to ensure that the tip of the needle has not traversed in the larynx or into the blood vessel.
- One or two ml of Lidocaine with epinephrine 1:100,000 is injected.
- The procedure may be repeated on the other side.

12. Transoral glossopharyngeal block

Some vallecular lesions cannot be adequately anaesthetised with the above methods. In such cases, glossopharyngeal nerve block is carried out. A small amount of the anaesthetic is injected 0.5 cm deep to the mucosa at the base of the anterior pillar, on both sides. This effectively anaesthetises the base of the epiglottis.

13. Laryngeal pathology suitable for office based surgery

13.1. Benign conditions

Many glottic and supraglottic pathologies are amenable for office based surgery, either with cold steel or laser procedures. Benign laryngeal pathology can occur as a single, stand-alone event, or as recurring pathology. Most polyps, cysts and nodules do not recur following successful surgical intervention when accompanied by management of underlying conditions such as vocal abuse or smoking.

Recurrent conditions such as respiratory papilloma, vocal process granuloma, leukoplakia or dysplasia are well suited for office based procedures which are much less time-consuming, have minimum down time, low morbidity and are considerably less expensive as compared to general anaesthesia (Rees *et al.*, 2006; Rees *et al.*, 2007; Zeitels *et al.*, 2004; Zeitels *et al.*, 2006; Zeitels *et al.*, 2007; Zeitels and Burns, 2007a; 2007b).

13.2. Biopsy

Biopsies can be obtained in two different ways, with a biopsy forceps passed through the working channel of the flexible endoscope, or, transorally. Biopsy through the working channel is a relatively easy method, but it lacks leverage to grasp and remove a sufficiently large tissue for histology. The transoral route requires a degree of dexterity and also cooperation from the patient. A curved forceps is passed via trans-oral route and the biopsy supervised with either a rigid or with a flexible endoscope. There is more leverage and a much larger specimen can be obtained via this route.

13.3. Cancer of vocal folds

Suspicious dysplastic lesions are biopsied in the office setting. Carcinoma *in situ* can be removed or ablated and followed up by repeat examinations. Therapeutic excision of a confirmed malignant T1 lesion is a possibility but can only be justified in patients with co-morbidity, unfit either for GA or for a course of radiotherapy.

13.4. BOTOX® injections

An office-based setting is also suitable for botulinum toxin injections. The conditions include spasmodic dysphonia, laryngospasm and paradoxical vocal fold movements. Botulinum toxin blocks acetylcholine release at the motor end plate, acting as a chemodenervating agent. The therapeutic effect is not permanent and requires repeat procedures, making management of these conditions particularly suited to office-based settings.

13.5. Vocal fold augmentation

A paretic or paralysed vocal fold fails to meet the contralateral side completely, producing weak voice. Atrophy of the cord, often associated with aging, leaves a central glottic gap. These gaps can be closed with fillers injected in the office setting.

14. Exclusion criteria

Office-based procedures cannot provide the accuracy that is achievable under paralytic general anaesthesia. Lesions on the free edge of the vocal folds need careful removal to ensure that the underlying vibratory structures are not damaged. This may be, but is not always achievable in the office on a moving vocal cord. Likewise, lesions on the under-surface of the vocal folds or within the laryngeal ventricle may be less accessible. Large, bulky and obstructing tumours are unsuitable for complete removal in the office. General anaesthetic-based procedures are often an appropriate choice, based on the need for precision, complete removal or management of the airway.

Anticoagulant therapy must be managed appropriately for both general anaesthetic-based as well as therapeutic office procedures.

15. Precautions

Patients may be advised not to eat or drink for a couple of hours before the procedure since they may feel retching due to gag reflex. It is also necessary to avoid intake of food or liquid for about 15 to 30 minutes after topical anaesthesia while the throat remains numb.

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MCQ – 58. Topical anaesthesia for office based laryngeal interventions

1. Topical anaesthesia for diagnostic and therapeutic laryngeal interventions has the following merit/s
    a. It can tackle most pathology
    b. It is cost effective
    c. It allows removal of tissue with a high degree of accuracy, both for diagnostic and therapeutic purposes
    d. It is particularly suitable for managing recurring pathology
    e. Subglottic and ventricular lesions can also be managed with a degree of competency

2. Following sensations are effectively suppressed with topical anaesthesia
    a. Gag reflex
    b. Cough reflex
    c. Pain
    d. Sensation of pressure
    e. Sensation of retching

3. It is possible to effectively anaesthetise the following sites with MAD device
    a. Base of the tongue
    b. Supraglottis
    c. Glottis
    d. Posterior part of the larynx
    e. Tip of the epiglottis
    f. All the above

4. Anaesthesia of the larynx through the working channel of the flexible endoscope requires preliminary anaesthesia of the
    a. Nasal passage
    b. Oropharynx
    c. Epiglottis
    d. Pharynx
    e. Base of the tongue

5. Under topical anaesthesia, it is not possible to
    a. Undertake precision phonosurgical procedures due to moving cords
    b. Undertake injection of fillers for glottic incompetency
    c. Undertake curative treatment for malignant lesion
    d. Undertake any procedure for obstructive lesions
    e. Tackle subglottic lesions

6. For topical anaesthesia
    a. A full explanation of the anticipated effect is most useful in getting patient cooperation in most cases
    b. An intravenous sedation must be given in nervous patients
    c. Patients are advised not to drive for a few hours
    d. Patient are advised not to take any liquids or solid food for a few hours
    e. Patient can leave the facility as soon as the cough reflex returns

7. Neurological regional blocks are
    a. Mostly not necessary
    b. Contraindications for the assessment of neurological lesions
    c. Useful in patients with excessive gag reflex
    d. Can splatter blood on the target site so that optimum surgery cannot be achieved
    e. All of the above

Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery, edited by V. Oswal, et al., Kugler Publications, 2014. ProQuest Ebook Central,

Chapter 59

The current status of flexible hollow waveguides for carbon dioxide lasers in head and neck surgery

P. O'Flynn

1. Introduction

CO_2 laser, emitting at 10,600 nm, is maximally absorbed by water. Airways are lined by mucosa, with high water contents. CO_2 laser is thus most suited for airway surgery.

One of the drawbacks of this useful laser is that it cannot be delivered to the target via optical fibre. The silica cannot be made completely anhydrous. The CO_2 laser energy is absorbed by the water in silica and its optical property is instantly destroyed.

The CO_2 laser is thus delivered as free beam to the target. Since light travels in a straight line, the target must be in the 'line of path' of the beam, thus restricting the application of this useful laser.

Fink *et al*. (1998) reported fabrication of an all-dielectric omnidirectional reflector consisting of multilayer films stacked as nine alternating micrometre-thick layers of polystyrene and tellurium. Coating of an enclosure resulted in an optical cavity, a hollow tube, which produced a low-loss, broadband *waveguide.*

The waveguide is not an optical fibre in its true sense, it is a hollow *wave-guide*, allowing omnidirectional propagation of CO_2 laser. However, the term fibre continues to be used to describe these waveguides. The author will thus address the various aspects of these waveguides by using the term 'CO_2 laser fibre' in the rest of this chapter.

2. Fibre characteristics

Currently, there are two commercially available systems based on the photonic band-gap principle: BeamPath by OmniGuide and Fibrelase by Lumenis. The CO_2 laser energy passes through a hollow CO_2 fibre confined by a series of concentric mirrors whose thickness and the gap between them corresponds to the wavelength of the CO_2 laser, *i.e.* 10,600 nm. The fibres are cooled by the passage of gas (air or helium) through the core.

As the beam emerges at the distal end, it starts to diverge. The concentration of the energy is maximal at the tip of the CO_2 fibre, and the waveguide is an efficient cutter when the target is in the near contact position. A diverging beam loses the concentration and the spot diameter enlarges. Reduced concentration of the energy is used to coagulate the blood vessels. Thus, when haemostasis is required the waveguide is moved away from the target.

The cutting and coagulating effect of the waveguide is thus no different than that of the silica optical fibre, and the operator has a full control to obtain the desired effect by adjusting the distance between the tip and the target (Fig. 1a, b).

Although the CO_2 fibre is flexible, it is relatively fragile and is readily damaged. If a fibre is flexed beyond its limits, any kink so caused will obstruct the flow of the gas. The heat from the energy causes the CO_2 fibre to become hot and eventually burn out.

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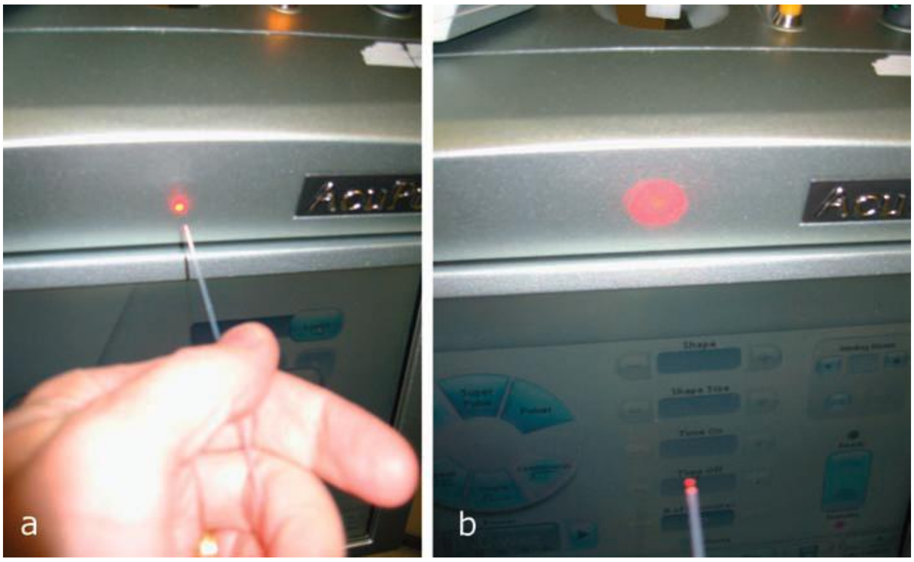

Fig. 1a, b. The divergence of the aiming beam used in the Lumenis product.

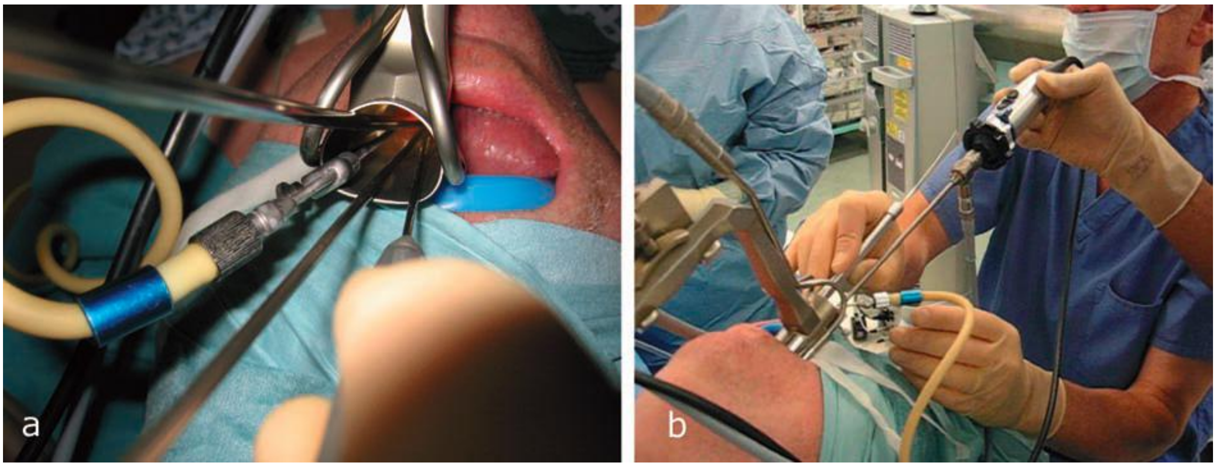

Fig. 2a, b. A typical set up for flexible CO_2 laser surgery via microlaryngoscopy set up with a 30-degree Hopkins rod.

2.1. Instrumentation for the delivery of the CO_2 laser via fibre

There are five essential components to the flexible fibre systems

- Laser – conventional base unit;
- A connection system to the fibre;
- The fibre itself;
- A supply of gas for cooling;
- Hand piece.

The various CO_2 laser units and their characteristics are covered amply throughout the various chapters, and will not be repeated.

The proximal end of the fibre is connected to the output portal of the base unit. The assembly has to be precise, since all the energy coming out of the portal must pass through precisely aligned hollow tube of the fibre without any leakage or obstruction. Mal-alignment will result in considerable thermal damage to the proximal end of the fibre and even to the base unit. Connection to the laser at the proximal end of the fibre remains an area of further refinement.

The two commercial systems differ in some aspects, summarised in Table 1.

The commercially available hand pieces, however, are very similar. A variety of lengths and angulations are available. Some of these are illustrated in Figure 3.

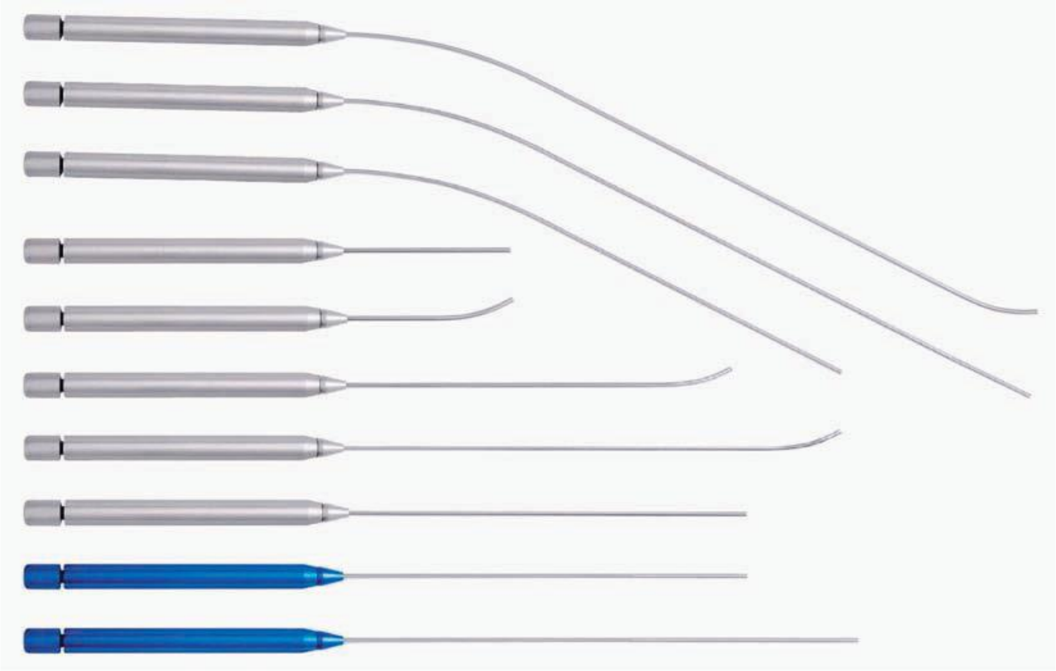

Fig. 3. Hand pieces.

Table 1. Comparison of OmniGuide BeamPath and Lumenis FibreLase

	OmniGuide BeamPath	*Lumenis FibreLase*
Cooling agent	Helium	Air
Aiming beam	Yes	No
Cleaving of fibre	No	Yes
Approx cost (based on 2012 figures)	£400	£550
Re-usable	No	No

3. Clinical applications

The CO_2 laser remains the workhorse laser for the airway surgery since its introduction in the seventies of the last century. However, its inability to pass through the optical silica fibre poses a considerable drawback. CO_2 laser surgery of lesions in some inaccessible areas which are out of the straight beam-path of the free beam could not be carried out, *e.g.*, posterior nose, nasopharynx, subglottis, the tongue base, etc. Availability of the CO_2 fibre has overcome this shortfall to a certain extent, although the current batch of the commercially available CO_2 fibres is not robust enough for its comparison with the silica optical fibres. Nevertheless, it is a step in the right direction. Within limits, the CO_2 laser fibre is flexible enough to address delivery of the CO_2 laser energy to the target situated round the corner, out of line of the direct 'free-beam' path.

There is another group of patients in whom anatomy or previous treatment makes free-beam access difficult. This group of patients include those with

- Prominent dentition;
- Overbite;
- Craniofacial abnormalities;
- Trismus;
- Spinal problems including fixation, kyphosis, rheumatoid arthritis.

In these patients, the CO_2 fibre can be used in conjunction with a flexible endoscope.

4. Protocol for the use of CO_2 laser fibre

- Dip tip of fibre in water to check gas flow;
- Test-fire on wooden spatula to confirm beam strike at distal end of fibre;
- Start with low energy setting, such as 5-10 watts;
- Since the beam diverges from the tip with reduction in power (unlike collimated beam) position the tip from the target to achieve the desired effect (near contact: cutting; at a distance: coagulating);

- Ensure laser safety protocol is followed by the theatre team;
- Energise the beam by pressing on the foot peddle.

5. Delivery of the fibre to the target

The fibre tip is be passed through the suspension laryngoscope while the target is monitored either with the operating microscope (Fig. 4) or with Hopkins rod (Fig. 5). The fibre can also be passed via instrument channel of flexible bronchoscope.

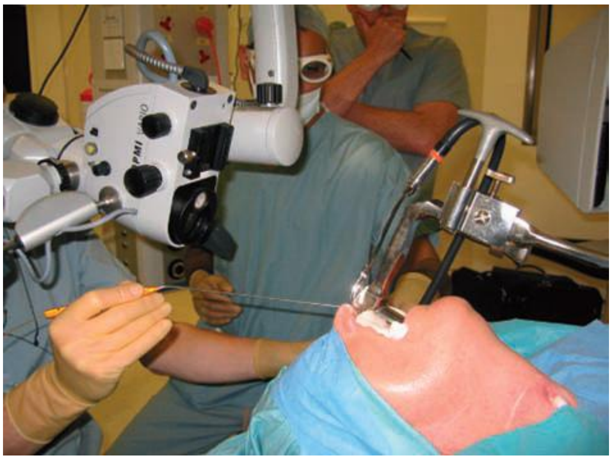

Fig. 4. The fibre is passed through laryngoscopy while the target is monitored with the operating microscope.

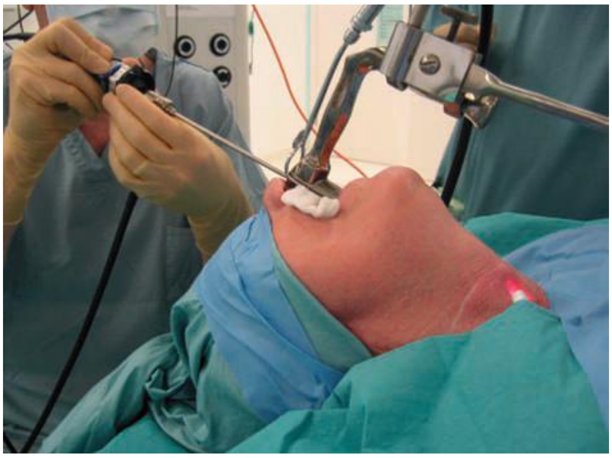

Fig. 5. The fibre is passed through laryngoscopy while the target is monitored with the Hopkins rod.

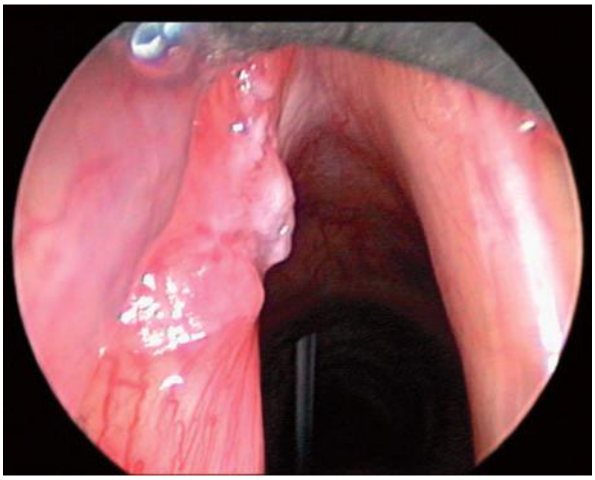

Fig. 6. Difficult access to an anteriorly placed squamous cell carcinoma. Note the trans-tracheal catheter in airway.

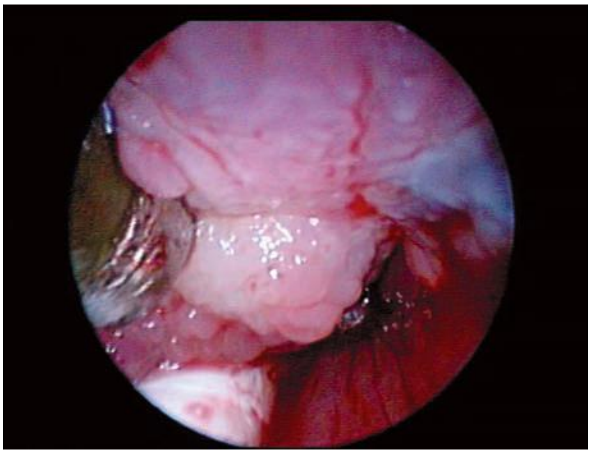

Fig. 7. A tongue-base lesion which is difficult to access with a free-beam delivery.

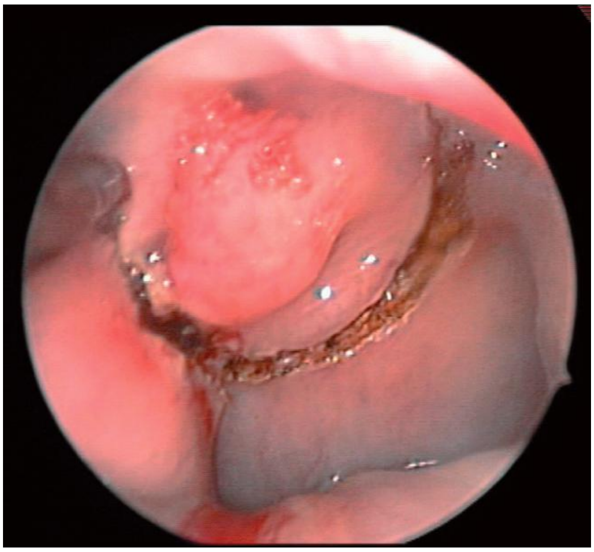

Fig. 8. Nasopharyngeal lesion – recurrence after chemoradiation therapy.

6. Clinical applications

Figure 6 shows a typical case where access to the anteriorly placed carcinoma is difficult. Tongue-base lesions (Fig. 7) are difficult to access with a straight hand piece with a beam stop, or as free-beam of the CO_2 laser. Angled hand pieces with fibre 'bend' the beam sufficiently to all areas of the lesion and facilitates its removal. Lesions of the nasopharynx (Fig. 8) are not amenable to excision with free-beam delivery since structures in the anterior nares obstruct the passage of the beam. There is also a risk of inadvertent strikes on the rim of the nostril which may cause unsightly scar. CO_2 laser fibre is particularly useful in the management of lesions in the posterior nose and the nasopharynx.

7. Conclusions

Flexible laser fibres are being used increasingly in surgery and in particular, in the Head and Neck region. They continue to develop and become more reliable. In combination with robots (Chapter 65) these fibres will open up even more inaccessible areas to surgical intervention. While the recently introduced FibreLase laser fibre (waveguide) can deliver the CO_2 laser reliably to inaccessible areas in the Head and Neck region, at present, its *routine* use is cost-prohibitive.

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MCQ – 59. The current status of flexible hollow waveguides for carbon dioxide lasers in head and neck surgery

1. Waveguide
    a. Waveguides are flexible silica fibres
    b. Waveguide is cleavable subject to manufacturer's specification
    c. Waveguide can be sterilised for repeat use in different procedures
    d. Waveguide are meant for single use in the same patient
    e. Waveguide should never be cleaved, should its tip be soiled during a procedure, instead, a new sterile waveguide should be used to continue the procedure

2. Flexible waveguide
    a. Flexible waveguide is most useful for UVPP since it gives a feedback and thus facilitates depth appreciation
    b. It is used in posterior part of the nasal cavity
    c. It is used in procedures in the subglottis
    d. It can be used in robotic surgery
    e. It comes in various lengths of hand-piece, for use in different locations

3. When using flexible waveguide, cooling gas is necessary
    a. To prevent tissues from heating excessively
    b. To cool the fibre since the heat from the laser energy causes the waveguide to get hot
    c. To prevent collateral thermal damage of the target tissue
    d. To ensure that the energy exits with precision alignment
    e. To prevent damage to the laser machine by cooling it

4. The cooling agent is
    a. Air
    b. Helium gas
    c. Air or Helium gas depending on the make of the waveguide
    d. Water
    e. CO_2
    f. Oxygen

5. Following are some of the drawbacks in the waveguide technology
    a. Waveguides are fragile and kink easily
    b. Their angulation is limited to a gentle curve
    c. The emerging beam is divergent and not focused and therefore requires a high power setting
    d. They require cooling gas
    e. The carry a single-use specification and are therefore cost-prohibitive for routine use

Chapter 60

Angiolytic lasers in the management of benign and malignant laryngeal disease and the establishment of office-based laryngeal laser surgery

S.M. Zeitels

1. Introduction

Endoscopic laryngeal surgery was introduced in the mid-nineteenth century as an office-based intervention and is one of the earliest examples of minimally-invasive surgery. In the early twentieth century, migration to the operating theatre occurred due to the advent of general anaesthesia, improved endoscopic instrumentation and the surgical microscope. Direct laryngoscopic techniques remained anchored to the operating theatre for much of the twentieth century.

Laser technology was initially reported for the vocal fold lesions in 1966 (Jako and Kleinsasser, 1966). The use of carbon dioxide laser to remove laryngeal tissue in the early 1970s is probably the earliest application to dissect and resect soft tissue in a human organ (Polanyi *et al*., 1970; Jako, 1972; Strong and Jako, 1972; Strong *et al*., 1973).

Angiolytic lasers were designed and developed on Anderson's concepts of selective photothermolysis in the early 1980s (Anderson and Parish, 1981; 1983; Anderson *et al*., 1983). In laryngeal surgery, the two fibre-based lasers, the 585-nm pulsed-dye laser (PDL) and the 532-nm pulsed-KTP (potassium-titanyl-phosphate) laser, have profoundly advanced the state-of-the-art surgery.

Introduction of distal-chip flexible-endoscopic technology provided much precision, and, coupled with the fibre-based lasers, office-based laryngeal *laser* surgery became feasible. Socio-economic forces further consolidated the concept of minimally-invasive office-based surgical technique which we introduced in November 2001.

2. Literature review

The concept of selective photothermolysis was conceived by R. Rox Anderson some 25 years ago for dermal vascular lesions. It is based on peak absorption coefficient of haemoglobin for wavelengths emitting at ~571 nm and ~541 nm. The pulsed-dye laser (PDL) emitting at 585 nm and the pulsed-KTP laser emitting at 532 nm are specifically and selectively absorbed by haemoglobin (Anderson and Parish, 1983; Anderson *et al*., 1983). The energy is delivered over a short pulse-width. It passes through the perivascular tissue and the vessel wall without significant absorption. It is maximally absorbed by the blood within the lumen, heating and coagulating it.

Selective heating of blood in the microcirculation without rupturing the vessel or causing collateral damage to perivascular tissue provides a platform for vocal fold laser surgery by angiolysis. After learning about vocal-fold phonatory function, Anderson stated, 'Treating vascular lesions in infant's skin is similar to treating vocal folds, pliability must be maintained or restored.' (personal communication R. Rox Anderson).

Based on its success in dermatology, pilot clinical studies were undertaken with the 585 nm yellow light Pulse-Dye-Laser (PDL) for laryngeal papillomatosis by Bower et al (Bower *et al*., 1998; McMillan *et al*., 1998). Shortly thereafter, Zeitels and Anderson initiated a large-scale investigation involving over 300 procedures for Recurrent Respiratory Papillomatosis (RRP) and other commonly recurring laryngeal mucosal pathology (Franco *et al*., 2002; 2003; Zeitels *et al*., 2004).

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3. New paradigm treatments

Since a number of mucosal lesions in the larynx comprise of aberrant and/or abundant microvasculature, a surgical model based on angiolysis is plausible. It was theorised that successful angiolysis would provide management of mucosal lesions in two different ways. Firstly, deprivation of blood supply would result in regression of the lesions. Secondly, preservation of layered microstructure of superficial lamina propria (SLP) and the epithelium from thermal damage would maintain the pliability of the vocal folds and contribute to the quality of glottal sound production.

Lesions which did not regress fully could still be removed with cold instrumentation.

Following these considerations, new angiolytic treatment paradigms were created for the following laryngeal mucosal lesions (Fig. 1):

- Mucosal dysplasia (Zeitels, 2001e; Franco *et al.*, 2003; Zeitels *et al.*, 2006)
- Papillomatosis (Zeitels, 2001a; Franco *et al.*, 2002; 2003; Zeitels *et al.*, 2004; 2006; Burns *et al.*, 2007)
- Early glottic cancer (Zeitels *et al.*, 2008)
- Ectasias, varices (Zeitels *et al.*, 2002a; 2003; 2006)
- Hemorrhagic polyps (Zeitels *et al.*, 2002a; 2006).

Early on, it was considered that the most appropriate lesions for the angiolytic lasers would be epithelial papillomatosis and dysplasia. The pulse dye laser (PDL) was used initially to raise microflaps, followed by cold-instrument epithelial resection. Dysplastic glottal keratosis was also successfully managed by photoangiolysis of the subepithelial microcirculation. The underlying superficial lamina propria (SLP), the primary oscillator during vocal-fold vibration, was spared (Zeitels, 1995). The out-

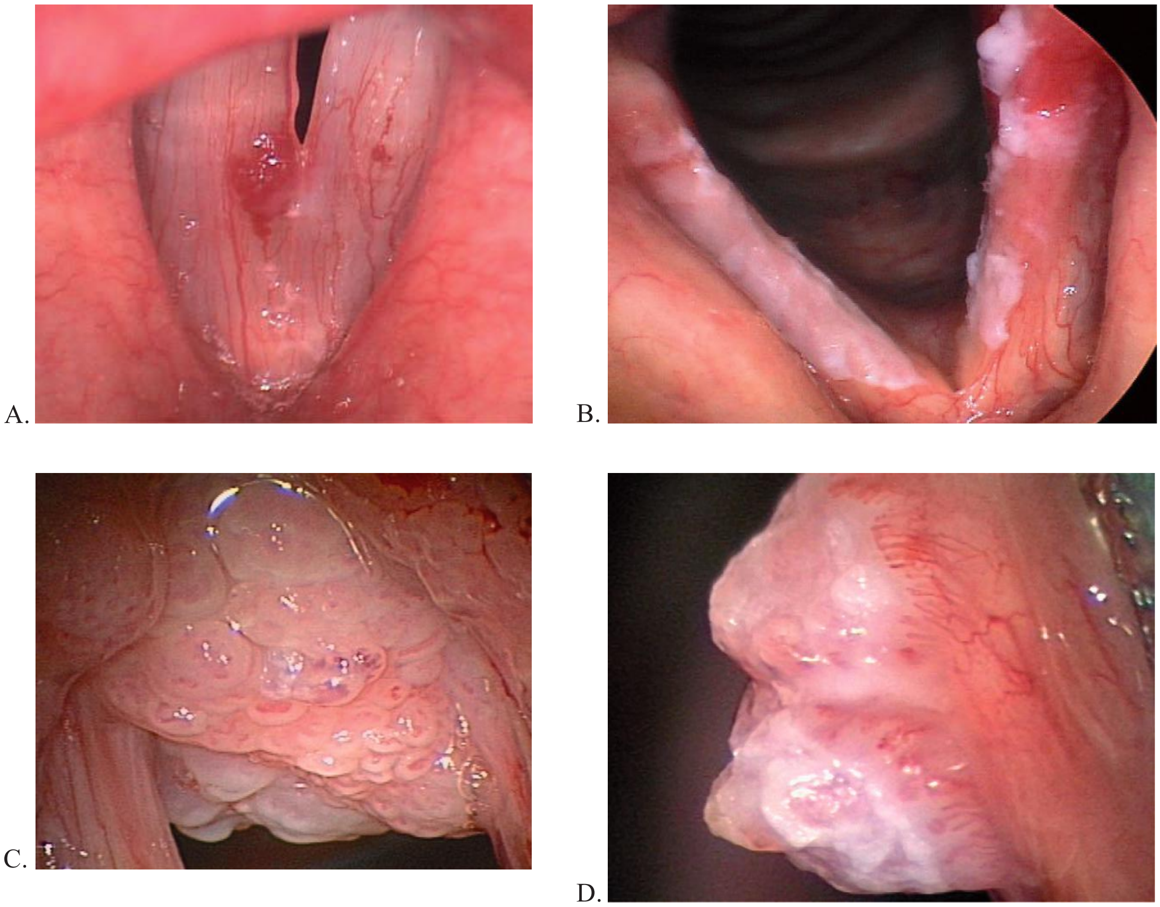

Fig. 1. A. Benign polyp with multiple varices and ectasias in a pop vocalist. B. Diffuse keratosis with dysplasia. C. Recurrent respiratory papillomatosis. D. Cancer.

come was very different from the frequently noted scarring of vocal fold, resulting from the CO_2 laser and/or cold instruments.

The management of these lesions is now routinely undertaken as an office-based procedure with topical anaesthesia (Zeitels *et al*., 2004; 2006). Our current data indicates that visible disease clearance can be as high as 75-100%, depending up on the extent of the glottal involvement. The procedure can be repeated as required. Although both the PDL and the pulsed KTP lasers were equally effective, in our experience, the KTP laser is substantially easier to use (Zeitels 2006; 2007; Zeitels and Burns, 2007) (see 4.3.2).

4. Basic science of angiolytic lasers

The presumed mechanism of disease regression is the *selective* destruction of the sub-epithelial microvasculature. This microvascular 'angiolysis' approach reduces the overall blood supply, leading to the ischemia of the diseased epithelium; as a result, both the survival of the existing pathology and any further growth are jeopardised. Basement-membrane-zone linking-proteins are denatured, leading to the separation of the epithelium from the underlying SLP (Gray *et al*., 1994). Tissue destruction is due to avascular rather than thermal necrosis and as such, is selective rather than gross. Thermal damage to the delicately layered microstructure (SLP) of the vocal fold is minimal.

4.1. Experimental work to characterise vessel wall rupture

To better understand and characterise observations related to vessel-wall rupture, basic science investigations were done (Broadhurst *et al*., 2007a; 2007b) Pulse dye laser and pulsed 532 KTP laser were used on microvasculature of avian chorioallentoic membrane. Vessel wall rupture occurred with PDL at pulse duration less than several milliseconds. KTP pulse-width could be adjusted for specific vasculature and therefore, there was no rupture of the vessels.

Suthamjariya and Anderson *et al*. (2004) carefully quantified haemorrhage as a function of pulse duration. The extended pulse-width capability of the KTP was a major therapeutic advantage. In dermatology, KTP laser at a pulse-width range of 10-50 ms resulted in purpura-free (nonhaemorrhagic) selective destruction of telangiectasia. These highly controlled studies on microcirculation of avian chorioallentoic membrane clearly established that the pulsed-532-nm KTP laser was superior to the pulsed dye laser for achieving vessel ablation without vessel-wall rupture and bleeding.

We confined the KTP pulse-width to ~15 ms to effect precise vessel ablation without heating and scarring of the extraluminal superficial lamina propria of the vocal fold.

4.2. Photothermolysis

Effective photothermolysis involves optimal fluence delivered *intraluminally* so that intraluminal blood coagulates instantly, completely and evenly. The parameters influencing the fluence are:
- Distance between the tip of the fibre and the target tissue
- The size, shape and calibre of the microcirculatory target, and
- The energy settings for each pulse.

If the fluence is delivered in a short, non-adjustable pulse width of ~0.5 millisecond (as in the case of PDL), it fails to coagulate the intraluminal blood completely and fully, so that some blood is still left in a fluid state at the end of the duty cycle of the pulse. Within this extremely short fluence range, the heating of the blood within the lumen is uneven, leading to vessel wall rupture. The uncoagulated blood flows out from the ruptured vessel, thus visibly covering and obscuring the operation site. The extravasated blood absorbs the laser energy and heats the delicate pliable superficial lamina propria of the phonatory mucosa (Zeitels *et al*., 2007; Zeitels, 2007b). In the setting of the office-based procedure, extravasated blood obscures the site of the operative field and often precipitates coughing, shortening the window of opportunity to apply laser energy.

4.3. Comparison of the 585-nm pulsed-dye laser and the 532-nm pulsed-KTP laser

Both 532-nm pulsed-KTP laser (Zeitels *et al*., 2006; Zeitels and Burns, 2006), and the 585-nm pulsed-dye laser (Zeitels, 2001; Franco *et al*., 2002; 2003; Zeitels *et al*., 2004) are now used widely for endolaryngeal surgery.

The PDL has the capability of involuting surface epithelial pathology without causing any collateral damage to the underlying phonatory, mucosal layered, microstructure. We used this useful effect of the PDL

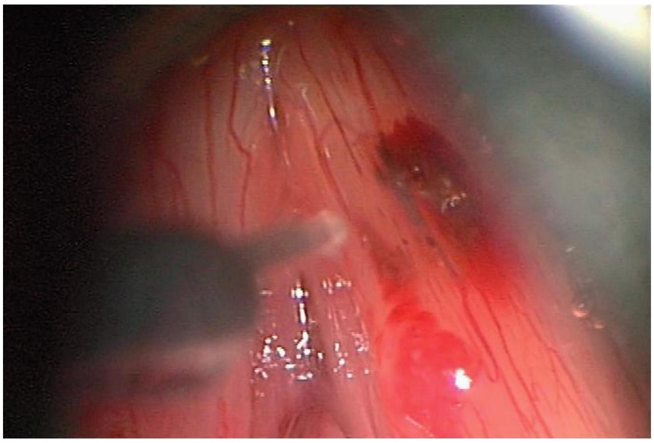

Fig. 2. Note that the target vessel is undergoing intravascular coagulation, while a collateral vessel to the right of the fibre sustains undesireable rupture and extravasation of blood.

for office-based laryngeal laser surgery way back in 2001 (Zeitels *et al*., 2004). However, we found that the PDL had some significant shortcomings, summarised below.

4.3.1. Pulsed-dye laser (PDL)

Despite the initial success of the 585-nm PDL for angiolytic surgery, there were some significant issues.

- It required a high capital outlay
- Not being a solid state laser, it frequently broke down, requiring repairs and replacing dye kits.
- If the power setting is changed during a procedure, the machine required recalibration.
- It has a very short, fixed, pulse-width (~.05 ms). This results in the damage of the vessel wall, with extravasation (Fig. 2).
- Extravasated blood will dissect into normal SLP surrounding the pathological tissue. The laser energy is absorbed by the blood covering the SLP and causes photothermal damage and scarring of this delicate phonatory layered microstructure.
- It required a fibre ≥0.6 mm, which was too large for some applications (Zeitels *et al*., 2007).

These factors reduced efficiency during the therapeutic window with local anaesthesia, which is frequently limited to ~30 minutes with topical lidocaine.

4.3.2. Pulsed-KTP 532 laser

We investigated solid-state 532-nm KTP laser in around 2005. The ease and precision of the procedures were greatly enhanced with the KTP laser (Zeitels *et al*., 2006; Zeitels and Burns, 2007). Its performance is summarised here.

- Strong absorption peak for oxyhaemoglobin.

Pulsed-KTP 532 laser emits at 532 nm, a wavelength that is more strongly absorbed by oxyhemoglobin than the 585 nm wavelength of the pulsed-dye laser. Strong oxyhemoglobin absorption ensures that very little energy goes to the vessel wall, thus avoiding its premature rupture due to thermal damage.

- Variable pulse width

More importantly, the pulse-width of the KTP laser can be adjusted. The pulse width was set at 15 milliseconds. The distribution of the energy extended and lasted some ~30 times longer than the PDL. There was complete coagulation of the intraluminal blood, no vessel wall damage and therefore, no extravasation. At this pulse width, we were able to treat papillomatosis and dysplastic lesions even in patients who were on anticoagulation regime.

- Fibre size

KTP fibre has a diameter of 300 or 400 nm, whereas the fibre diameter for PDL is 600 nm. Relatively smaller size of the KTP fibre allows more room for suction of plume and secretions, thus enhancing the efficiency of the procedure (Fig. 3). This is a key advantage when performing office-based laser surgery with a flexible laryngoscope and local anaesthesia.

- Intra-procedure calibration

Unlike PDL, KTP does not require recalibration if the power setting is changed during the procedure.

In the past, the KTP laser has been used successfully for subglottic haemangiomas as well as vocal-fold ectasias and varices (Kacker *et al*., 2001). However, the laser was used in a continuous-wave mode. In this mode, the epithelial surface and extraluminal soft tissue ablation is inevitable (Hsiung *et al*., 2003). A KTP laser in continuous wave mode will heat and ablate overlying epithelium similar to a CO_2 laser, which is not a desired outcome.

It is therefore important to note that the KTP laser must be used in *pulsed* mode to exploit its angiolytic property, with a minimal collateral extravascular thermal damage.

The authors now invariably prefer the angiolytic 532-nm KTP laser for laryngeal lesions since it can be used for office-based procedures as well as in the operating-theatre (Burns *et al*., 2010). However, lesions facing medially do pose a problem since side firing fibres are not available.

The pulsed KTP laser was successfully used to affect a reliable involution of phonotraumatic microcirculatory angiomata in the extremely delicate phonatory mucosa of performing vocalists (Zeitels *et*

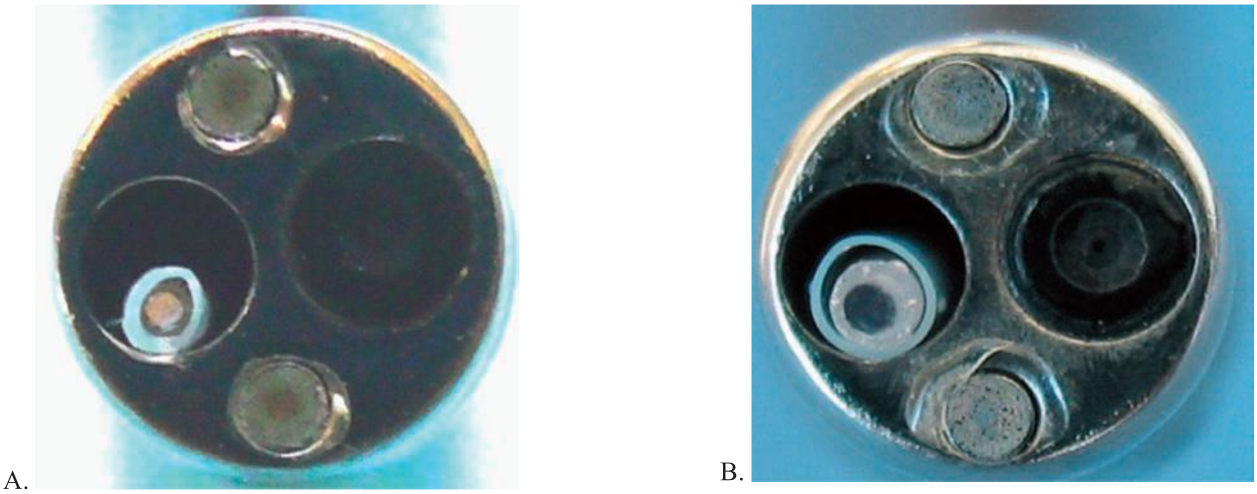

Fig. 3. A. The distal view of a distalchip flexible laryngoscope. A 0.3-mm KTP laser fibre with a sheath preserves a majority of the working channel to suction secretions and plume. B. The 0.6-mm fibre and sheath utilise substantially more area of the channel.

al., 2006). This landmark work received substantial attention and the technique was highlighted in the Wall Street Journal, the London Sunday times and in a National Geographic documentary, featuring Steven Tyler's (Aerosmith, American Idol) microsurgery (Fig 4).

5. Office-based angiolytic laser treatment

For anaesthetic technique see Chapter 58.

Successful management of Glottal dysplasia (Franco *et al.*, 2003) and papillomatosis (Franco *et al.*, 2002) with 585-nm pulsed-dye laser under general anaesthesia prompted us to develop a strategy for similar management as an office-based procedure (Zeitels, 2004).

5.1. Pros and cons of office-based laryngeal surgery

It is important to appreciate that the office-based laryngeal surgery under topical anaesthesia poses some inherent problems and limitations.

- The 'target' under topical anaesthesia, is a moving target.
- The distance between the tip of the fibre and the target cannot be quantified for consistency from a viewing monitor.
- Medially facing lesions cannot be treated optimally since side firing fibres are not available.
- Two-dimensional view of the operating procedure lacks the accuracy of the binocular operating microscope.
- When using flexible laryngoscopes, there are unavoidable tangential vectors for visualisation and laser delivery, which cannot be overcome by bimanual tissue retraction and facile fibre alignment.
- A specimen for histopathological analysis is not routinely obtained as part of a decision-making process for treatment, although taking a biopsy with a cupped forceps is certainly easy to do with local anaesthesia, it is often not as precise as in the operating room and will typically cause some minor bleeding. The time to retrieve the biopsy can diminish local anaesthesia time for therapeutic management.
- The blood at the operative site will absorb the angiolytic laser and reduce its desired effect on microvasculature.
- If the surgeon is not experienced, and the laser is not used precisely, the absorbed energy can result in heating and damage of soft tissue microstructure of SLP and the epithelium, and heal with a scar.
- Patients with 'condemned' glottal mucosa (ongoing erythroplastic or keratotic dysplasia) may undergo several procedures per year similar to those with RRP.

5.2. Indications for office-based procedures

Reduced morbidity associated with local anaesthesia in the clinic considerably facilitates the treatment of older patients, particularly those with substantial cardiovascular and pulmonary disease not uncommon

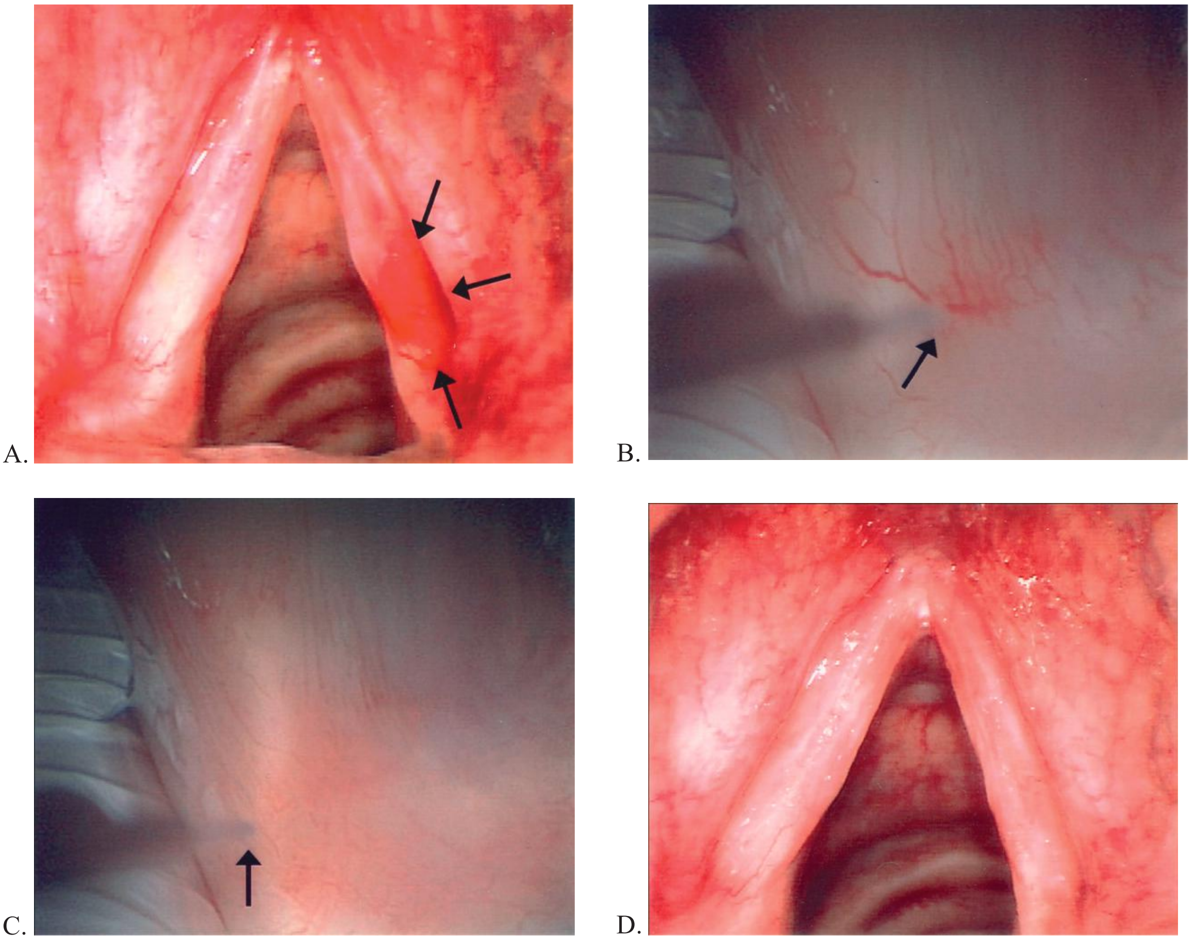

Fig. 4. A. Steven Tyler, vocalist from Aerosmith, hemorrhaged into his right vocal fold in 2006 inhibiting his ability to perform. B. The 0.3-mm fibre of the 532-nm pulsed-KTP laser is directed towards the offending varix. C. The regional microcirculation is involuted without vessel-wall rupture or disturbance of the overlying epithelium. D. Since angiolytic pulsed KTP-laser treatment he has not had another bleeding episode and did not sustain vocal deterioration.

in aging societies and in societies with greater prevalence of tobacco use. In the younger and working population, there is less lifestyle disruption if a general anaesthesia in the operating room is avoided. Following our introduction of office-based angiolytic laser laryngeal surgery (Zeitels, 2004), a number of surgeons have adopted this paradigm shift. It is likely that this approach would be more widely implemented if the endoscopic and laser instrumentation were less expensive.

Based on an extensive experience of treating >1000 cases of laryngeal papillomatosis and dysplasia with the angiolytic KTP laser, we believe that this technology provides a substantial advance. It is likely that there will continue to be further innovations in endoscopic and laser treatment strategies. Despite the effectiveness of office-based management, glottal papillomatosis and keratosis should not be treated by means of local anaesthesia without a prior histopathological diagnosis and an established pattern of recurrent disease.

5.3. *Contra-indications for office-based procedures*

At present, we do not support the routine use of office-based angiolytic laser management of polyps, ectasias and varices unless a single general anaesthesia is contraindicated. Although these phonotraumatic lesions can be treated in the clinic with varying degrees of involution, office-based treatment can require multiple staged procedures, which is not appropriate for lesions that can typically resolve with one operation. Simple debulking of lesions and leaving residual fibrovascular tissue predisposes to early symptomatic recurrence due to residual aberrant soft tissue. Furthermore, these lesions are typically encountered in patients in whom general anaesthesia is not a significant risk and precision is critical (*i.e.*, performing vocalists)(Zeitels, 2001; 2002a). Phonotraumatic lesions are optimally managed with a comprehensive microlaryngoscopic examination including palpation and retraction of vocal tissues. We believe that mass lesions arising in the superficial lamina propria of the phonatory mucosa should be resected by means of bimanual phonomicrosurgical techniques using pulsed-KTP laser (Zeitels, 2002a; 2006b).

If the procedure is expected to last longer than 30 minutes, the office-based procedure is contraindicated since the topical anaesthesia would be ineffective and reapplying lidocaine could lead to toxicity.

Nervous and uncooperative patients are obviously not suited.

5.4. Equipment and instrumentation

Our clinical office-based experience treating these lesions exceeds 200 cases with the PDL and more than 800 cases with the pulsed-KTP laser. These procedures are well tolerated, even by elderly patients (Zeitels, 2004; Rees *et al.*, 2006; Zeitels 2006). These lasers are used along with a Pentax model VNL-1530T flexible laryngoscope. Visual guidance is achieved by observing the glass fibre through the distal working channel of the laryngoscope, which has a 2.0 mm internal diameter and a 5.1 mm outer diameter. While the VNL-1530T flexible laryngoscope still uses optical fibres for illumination, superior higher resolution-imaging capability is provided via the placement of the CCD video chip in the distal end (examination tip) of the scope.

6. Recurrent respiratory papillomatosis and precancerous dysplasia

In the latter part of the twentieth century, the treatment goals for glottal papillomatosis consisted of removal of disease with microsurgical techniques and cold instrumentation. Introduction of laser technology saw a shift in the management, but initially, the goal remained the same: removal of disease and minimise recurrence rate.

Earlier lasers lacked finer controls of exposure time and spot size. Collateral thermal damage was inevitable, affecting the delicate phonatory structures. Introduction of superpulse, scanning accessories, acuspot and acublade was a welcome advance and minimised collateral damage. However, these procedures had to be undertaken under general anaesthesia, which remains a liability since a significant number of patients require frequent and multiple procedures due to the aggressive nature of their disease. Moreover, each CO_2 laser procedure does leave behind a zone of thermal damage, however miniscule (~50 um), with eventual loss of vocal fold layered microstructure. Such repeat procedures with CO_2 laser may result in a loss of vibratory surface and even glottal competency, leading to a poor voice quality.

Thus, treatment goals should be temporised particularly in patients who require frequent repeat procedures. Disease regression and voice preservation/restoration need to be weighed against morbidity and cost of the intervention. Based on an extensive experience of treating >800 cases of laryngeal papillomatosis and dysplasia with the angiolytic KTP laser, we believe that this technology provides a substantial advance on the conventional management. It is likely that there will continue to be further innovations in endoscopic laser treatment strategies.

6.1. Adjuvant anti-angiogenic treatment

Our most recent innovation is comprised of treating patients with severe RRP with the antiangiogenic drug bevucizamab (Avastin) combined with angiolytic laser treatment, which has provided a profound improvement in the management of our recalcitrant cases.

In 1971, Folkman isolated the first tumour-derived antigenic factor and proposed that tumours require new blood vessels to grow and multiply. He next proposed that tumours not only provided growth substances for angiogenesis, but also that cancers were absolutely dependent on these factors in order to survive and kill their hosts. It seems appropriate to speculate that the inhibition of angiogenesis, *i.e.*, anti-angiogenesis, may provide a form of cancer therapy worthy of serious exploration

Neovascularisation takes place as a result of the biologic activity of human vascular endothelial growth factor (VEGF). Bevacizumab (Avastin) binds to and neutralises the VEGF. Photoangiolytic lasers effectively treat glottal papillomatosis, but do not reliably prevent recurrence. Therefore, we conducted a retrospective study with sublesional injections of the antiangiogenic agent bevacizumab (Avastin) on a pilot group of ten adult patients with bilateral glottal papillomatosis

Five bevacizumab injections (5-10 mg) were given into the diseased vocal folds along with 532-nm pulsed KTP laser photoangiolysis treatments, four to six weeks apart. Their disease resolution was compared to findings from prior laser treatment alone, and objective measures of vocal function (acoustic, aerodynamic, Voice-Related Quality of Life survey) were obtained. All ten patients had a greater than 90% reduction in recurrence. Four of the ten had resolution. Further four had limited recurrent or persistent disease. These received injections of bevacizumab at 8-12-week intervals, and did not required laser treatment. Two of the ten required ongoing periodic office-based KTP laser treatment along with bevacizumab injections. No patient has required microlaryngeal surgery with general anaesthesia, and all ten have had substantial improvement in vocal function.

This pilot investigation provides preliminary evidence that bevacizumab injections enhance photoangiolytic laser treatment of glottal papillomatosis while preserving or improving phonatory function. Pursuant to this initial study, we have now performed in excess of 200 Avastin injections to enhance KTP laser treatment of RRP without a local or systemic complication. The results from a highly successful clinical trial with a United States FDA investigational new drug exemption confirmed the findings of the pilot study. Coupling an antiangiogenesis agent with pulsed KTP laser photoangiolysis is conceptually promising, since the mechanisms of action are complementary (Zeitels *et al*., 2009).

6.2. Evaluation of angiolytic treatment for RRP

Although treatment of epithelial dysplasia and RRP using the 532-nm pulsed-KTP laser is very effective it is difficult to study disease involution precisely in these patients, since, similar to laryngeal dystonia population seeking a Botox injection, the majority only return when they are in need of a procedure due to recurrence of their symptoms. Furthermore, many patients are required to travel long distances for the treatment advantages afforded by this management strategy.

7. Management of early glottic cancers with angiolytic lasers

Zeitels *et al*. (2008) reported a new philosophy for treating *early* vocal cord cancer. Instead of conventional *ablative* laser treatment, they used angiolytic lasers to involute the neoplasm. The non-ionising laser energy was micro-surgically directed in the dense neoplastic blood supply. As a result of angiolysis, the neoplastic tissue involuted, and at the same time, soft tissue of the vocal fold was maximally preserved. Thus, a cure was achieved with maximal retention of vocal function.

At the time of writing, their experience related to over 150 cases (T1 and T2) with ~90% cure rate. This approach is thus conceptually attractive since it is repeatable, preserves all conventional options for cancer-treatment, and results in excellent vocal function by optimally preserving phonatory mucosal-wave vibration. Observations from this investigation suggest that this new cancer-treatment strategy is plausible. However, larger patient cohorts and multi-institutional confirmation is necessary to establish incontrovertible oncologic efficacy

The new technology needs to produce predictable results in statistically significant number in multicentric cohorts. The outcomes should be comparable or better than the conventional mode of treatment. A complication rate should be similar or lower than the existing methods. The skill level required should be average and not so high that only a few in the profession could practice the technique. Finally, the capital outlay and the revenue costs are influencing the healthcare systems the world over. Emerging technology thus has to progress through the acrimony of controversies before relatively calmer shores of consensus.

8. Indications for office-based treatment

Non-malignant chronic epithelial pathological conditions (dysplasia and RRP) are the key indications for office-based laser treatment. Our most recent innovation is comprised of treating patients with severe RRP with the office-based subepithelial injections of the antiangiogenic drug bevucizamab (Avastin) combined with angiolytic laser treatment, which has provided a profound improvement in the management of our worst cases (Zeitels, 2009).

9. Varices and ectasias in professional voice users

Endolaryngeal surgery on the musculo-membranous vocal folds in performing artists has been a challenge since the beginning of our specialty, 150 years ago.

We have been investigating surgical management of ectasias and varices for over a decade (Hochman *et al.*, 1998; Zeitels, 2001d; 2002a; 2006b). The surgeon, patient, and voice teacher/coach must assess whether the vocal liability of the lesion(s) justifies the risk of surgical intervention (Zeitels, 2002a).

Impaired vocal performance due to recurrent glottal haemorrhage from ectasias and/or varices may or may not be associated with a mass lesion such as a polyp, a nodule or a cyst. A decision to manage mass-associated ectasia is relatively easy since the voice performance is significantly impaired and frequently requires surgical treatment. Ectasias can be managed simultaneously.

Ectasias unassociated with a mass lesion produce voice impairment intermittently when bleeding occurs. The offending lesion is in close proximity of the phonatory structures. Surgical dissection of ectasias to reduce the frequency of bleeding bears a considerable risk of damage to the phonatory structure.

The obvious problem with a vocal haemorrhage is that performances are missed, recurrent bleeding and inflammation in the SLP results in detrimental stiffness (scarring) of the phonatory mucosa and associated voice deterioration. Imprecise surgical treatment of episodic bleeding from small varices and ectasias leads to increased stiffness of the superficial lamina propria, thereby irreparably diminishing vocal quality.

Although the treatment of ectasias and varices in singers with cold-instrument dissection has generally been satisfactory (Hochman, 1998; Zeitels, 2001d), it is technically difficult, requires multiple epithelial cordotomies, and is very time-consuming. CO_2 laser or electrocautery potentially could lead to thermal damage of SLP with a risk to permanent voice impairment.

Based on our experience with angiolytic laser in the management of epithelial disease, we extended the use of the pulsed KTP laser to a non-contact management of ectasia to involute the lesions. The procedure was associated with lack of thermal damage of the SLP.

As compared to cold instrumentation, the time taken to treat ecstasias was much shortened with the pulsed KTP laser. Our results showed that all patients returned to active singing (Zeitels, 2006b). They were free from any further episodes of bleeding. A majority reported improvement in quality and reliability of performing voice. A minority experienced no improvement in their voice quality, but were pleased to be free from recurrent bleeding episodes.

The parameters of the pulsed KTP were as follows:

- Pulse width: ~15 ms
- Power: ~450 mj
- Fibre-to-tissue distance: 1-3 mm

When ecstasias were without concomitant mass lesion, they were coagulated without thermal damage. When there was a mass lesion with a feeder vessel, we used pulsed KTP laser within the SLP to obliterate the feeders while simultaneously removing the mass lesion with cold instrumentation.

10. Glottic cancer

10.1. Basic science

Angiolytic KTP 532 laser provides non-thermal, non-ionising radiation energy over an extremely short pulse width of ~15 ms. The angiolysis results in involution of the lesion due to compromised blood supply. Remarkably, the constituents of the method described herein were identified almost 40 years ago. Whereas Kleinsasser described the aberrant microcirculation (Fig. 5) associated with microinvasive vocal fold carcinoma, Jako had already commenced investigations in to the use of laser technology: 'Experiments using laser beams for destruction of discrete areas of vocal cords are presently being conducted' (Jako, 1966).

Conventional microlaryngeal laser techniques with CO_2, continuous-wave KTP or Thulium lasers are used exclusively as a scalpel for gross ablation of the neoplastic malignant pathology. Pulsed-angiolytic lasers, on the hand, concentrate the energy *within* the dense aberrant angiogenic microcirculation of the tumours without penetrating deeply into the normal soft tissue of the vocal fold. By confining the pulse-width to ≤ 15 ms, the angiolytic laser induces selective heating of the intralesional/subepithelial microcirculation of the lesion. The result is the minimum thermal trauma and subsequent fibrosis of the extra-lesional normal glottal soft-tissue, thereby optimising mucosal pliability, necessary for vibration.

Although angiolytic laser acts as radiation and not as scalpel to affect the target tissue, there are considerable differences in their action.

- Video-stroboscopic examination following radiotherapy suggests that both normal and cancerous tissues often reflect fibrotic changes (Lehman, 1988). This is especially so when a neoplastic glottal lesion also causes collision

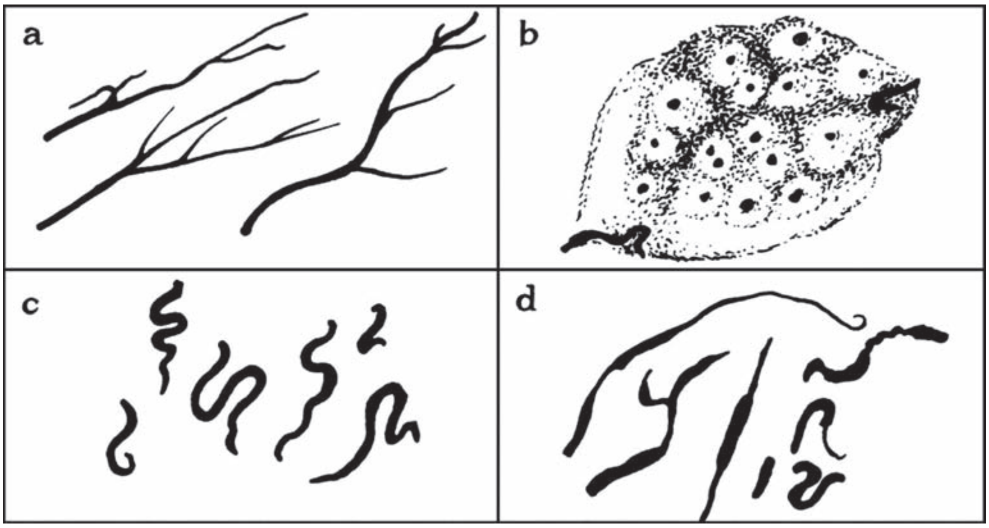

Fig. 5. a. Vascular pattern of normal arborizing microcirculation seen through the transparent epithelium and within the superficial lamina propria of the phonatory mucosa. b. precancerous dysplasia of the epithelium obscures visualisation of the subepithelial microcirculation. c and d. invasive carcinoma is comprised of aberrant disordered and dense microvasculature (Jako GJ, Kleinsasser O, 1996).

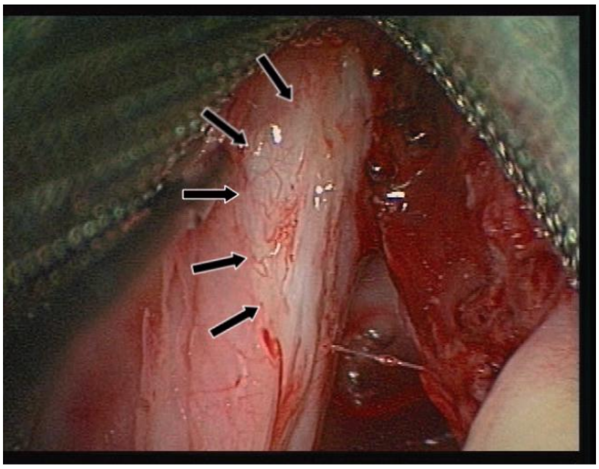

Fig. 6. A patient developed extreme hoarseness subsequent to radiation failure of a unilateral right-sided glottic cancer. Note the crescent-shaped region outlined by the arrows where the regenerated epithelium is adherent to the stiff white vocal ligament. The pinker area in the arm of the arrows reflects residual SLP. Unfortunately, the residual SLP is at the perimeter of the key phonatory zone of the remaining functional vocal fold.

trauma to the contralateral phonatory mucosa during acute radiation mucositis (Fig. 6). Pulsed-angiolytic lasers concentrate the energy solely to the region of the cancer due to its increased vascularity, with a several millimetre margin. Therefore, non-cancerous glottal/phonatory tissue is not treated or affected.

- Laser irradiation does not damage the ventricle saccule glands (Tucker, 1971), which provide surface hydration, critical for optimal glottal vibration and sound production.

If the lesion is deep in to the paraglottic space, conventional treatment may damage the underlying normal paraglottic tissue, resulting in glottic incompetency. In superficial tumours, conventional treatment will cause fibrosis of the SLP. Thus, in both cases, the quality of voice is poor. However, since treatment with angiolytic laser concentrates on vascular supply, it spares both normal paraglottic tissue as well as uninvolved SLP. The voice quality following angiolytic laser is thus much superior.

Conventional cancer treatment is carried out using three modalities: surgery, radiotherapy and chemotherapy. These are based on the science of biology, physics and chemistry.

Jako, Strong and Vaughan (1972) used the CO_2 laser initially for dysplasia some 30 years ago. The successful outcome prompted them to extend its use to intraepithelial, early glottic cancer. We mirrored this experience for angiolytic laser. Its initial success with glottic dysplasia prompted us to logically extend its use for intraepithelial, early glottic cancer, with an anticipated successful outcome.

Vocal folds are a unique site to study localised minimally-invasive cancer of the upper aerodigestive tract. Removal can be staged since the presence of intercurrent disease (between the treatments) rarely metastatises and thus does not constitute additional risk to the patient. For example, the tumour involving the anterior commissure can be cut through and the disease is removed only on the side that is extensively involved. The remaining tumour can be treated subsequently at the second operation some six weeks later, in the secure knowledge that the intercurrent disease left behind at the first operation will only rarely metastatise. This staged procedure is entirely appropriate and does not represent added risk to the patient. Anterior glottic stenosis or web formation is thus avoided, resulting in improved vocal outcome.

By employing Dr. Folkman's concepts (Fig. 7) of tumour angiogenesis (see 7.1), we pursued extension of indications for angiolytic lasers from dysplasia to limited areas of early vocal-fold cancer to test the hypothesis of disease involution.

We initially chose to treat the non-dominant vocal fold in a highly selected population of patients with bilateral glottic cancer due to the dramatic detrimental effect on airway and/or voice from standard surgical and radiotherapeutic regimens. It was felt that if successful, this approach could substantially enhance the postoperative voice without significant risk to the patients because:

- The disease was of small volume
- Early glottic cancer is slow growing and rarely metastasises
- Patients with early glottic cancer are easy to follow closely during the postoperative healing period and to intervene immediately if clinically appropriate
- Our routine plan would have been to perform a microlaryngoscopic resection of the second vocal fold in a staged fashion to avoid anterior stenosis
- All conventional treatment options remain available.

Anti-angiogenesis (Folkman, 1971; 1995) agents (see 7.1) may be considered the fourth modality for cancer treatment. However, just as other modalities, antiangiogenetic agents are also used as an adjuvant with other conventional treatment modalities. Angiolytic lasers are used as single modality treatment and therefore may be considered as a truly standalone fifth modality (Dr. J. Folkman, personal communication).

10.2. Incremental endoscopic surgical management of early glottic cancer

Early glottic cancer has certain characteristics which makes it unique to use specific treatment modality, unsuitable for similar cancers at other sites of head and neck.

- Patients with glottic cancer present early on account of symptom of hoarseness which interferes with their daily activity.
- At presentation, the volume of neoplasm is small, compared to other sites in the upper aerodigestive tract.
- Glottic cancer rarely metastasises.
- If RXT is chosen as treatment modality, the tumour receives serial incremental dosage over a period of six to eight weeks.

If one were to introduce a staged *incremental, endoscopic surgical* management of early glottic cancer over a period of six to eight weeks, it will be entirely commensurate with the other modalities, employed singly or in combination.

10.3. Comparison of management of early glottic cancer with angiolytic laser versus RXT

We considered a conceptual management of early glottic cancer with angiolytic laser as an extension of our experience of the successful outcome treatment of glottal dysplasia with angiolytic laser. We set out to establish proof-of-concept to involute the early glottic cancer by using the angiolytic laser treatment in a highly selective cohort of patients.

Our data thus far supports a proof-of-concept that microinvasive cancer can be involuted by means of pulsed photoangiolysis and that mucosal function / pliability can be maintained/restored (Zeitels, 2008).

The critical selection was based on early glottic cancer without impaired vocal fold mobility. While we are guardedly optimistic about the oncologic efficacy of this new technique, we believe that it will require larger cohorts, longer follow up, and multi-institutional confirmation.

When compared to the conventional management of early glottic cancers without impairment of the vocal fold mobility with RXT, there are a number of advantages of employing angiolytic laser.

- Ionising radiation of RXT can be given only once. It cannot be used for recurrences; neither can it be used for secondary primary in the irradiated area.
- Gross non-concentrated and non-selective effects take in the tissue which is otherwise normal: *e.g.*, glands of the saccule, uninvolved ipsilateral and contralateral phonatory mucosa and SLP.
- Radiation induced mucositis of the affected cord can result in phonotrauma of the contralateral side.

Fig. 7. Judah Folkman (1933-2008).

- Stomatitis and dry mouth are not uncommon.
- The course is time consuming, and is associated with certain degree of general morbidity.
- Healing with fibrosis is set to give inferior phonatory outcome.

Management of comparable lesions results in involution of cancer without any of the above disadvantages:

- The radiation of the angiolytic laser is non-ionising and thus can be used repeatedly for any recurrence or second primary.
- The energy is selectively absorbed by microvasculature and thus saccular glands, uninvolved phonatory mucosa and SLP are spared.
- There is no associated morbidity or stomatitis.
- Phonatory outcome is to be expected as superior to RXT due to above factors.
- Time frame for treatment is shorter than that for RXT.
- All other surgical and radiotherapeutic treatment options are preserved.

In excess of 80% of T1 lesions are superficial and do not invade through the vocal ligament to the thyroarytenoid muscle (Zeitels, 2002b). In fact, ~50% do not invade through the SLP to the vocal ligament (Zeitels, 2002b). If over time, oncologic success is confirmed at other institutions, we believe that reasons above should make this approach a standard first line treatment in these highly selective cases of early glottic cancer without impairment of vocal fold mobility.

10.4. Bilateral and anterior commissural glottic cancer

If adequate laryngoscope exposure is achieved, management of the anterior commissure is not problematic. Maintaining the architecture of the anterior commissure and rima glottidis by splitting the tumour and separating the treatment is unlikely to have a negative impact on the patient. (Desloge, 2000) We have had success in this regard with intraepithelial dysplasia for a decade (Zeitels, 1995; 2001e) and we do not believe that early glottic cancer requires the same urgency of complete tumour eradication as other sites of the head and neck.

10.5. Voice ramifications

Hirano (1975; 1977; 1985) championed the assimilation of functional vocal physiology into the design of glottic cancer surgery.

Effective vocal-fold oscillation is primarily achieved by:

- Maintaining/restoring aerodynamic glottal valvular competency, and
- Optimising pliability in the cancerous vocal fold by minimising trauma to the residual normal SLP.

The voice results following treatment with angiolytic laser are typically superior to what we have been able to obtain in the past. The maintenance and/or improvement of vocal function is due to the angiolytic property of the pulsed 532 KTP laser's capability to resolve the tumour while optimally preserving or restoring vocal fold pliability through conservation of non-cancerous superficial lamina propria. This assumption is supported by subjective stroboscopic observations of improved postoperative mucosal wave activity (Fig. 8).

To this end, we advocate ultra-narrow margins (Zeitels,1996; Remacle, 1997) along with phonosurgical reconstruction (Remacle, 2001; Zeitels, 2001e; Burns, Kobler *et al.*, 2004) to establish normal conversational-level voices (Zeitels, 2002b).

In unilateral disease, the main oscillator for glottal voice is the contralateral superficial lamina propria and the voice outcome can be very satisfactory. In bilateral disease, fibrosis and stiffness in both vocal folds typically results in an extremely hoarse and perturbated voice. Even in those patients, the angiolytic laser produces better voice outcome. There are a number of reasons for the improved voice, all of which can be explained by improvements in post-treatment aerodynamic competency of the glottic and/or enhanced phonatory mucosal pliability through better preservation of superficial lamina propria, the layer necessary for glottal vibration (Zeitels, 2002b).

Building superficial lamina propria with substitutes may be possible in the future to restore a completely normal voice as measured by maximal range tasks of pitch (frequency) variation and loudness (amplitude) (Zeitels, 2007c).

By evaluating the spectrum of geographic presentations of early glottic cancer, specific scenarios can be understood. In T1a lesions in which the cancer has not fully replaced the SLP and invaded the vocal ligament, the postoperative mucosal wave may be substantially restored for optimising voice outcome. Since ~50% of all glottic cancers fall in to this category, an excellent overall voice outcome can be anticipated (Zeitels, 2002b).

In patients with T1b lesions, staging the treatment so that a small amount of tumour is left at the extreme medial surface of the anterior commissure substantially improved the voice outcome as compared with any conventional (cold instrument or CO_2 laser) single event surgery. Similar to Kirchner (Kirchner 1989), we did not encounter any patients with a T1b lesion in which mucosal involvement across the anterior commissure was accompanied by invasion through the anterior commissure tendon (Broyles ligament (Broyles, 1943)) to the thyroid cartilage. Furthermore, in all 12 bilateral cases, one side was significantly much more extensive than the other side. The contralateral vocal fold had substantially intact superficial lamina propria beneficial for glottal vibration. By staging the treatment and separating the disease anteriorly and preserving some of the residual SLP in the contralateral vocal fold, we could functionally simulate the voice results previously achieved with unilateral disease.

10.6. Translation of the technique

As high-tech medicine advances, it, of necessity, becomes complicated, expensive and demands high skill level. Robotic surgery stands as an example of recent years. We developed the chick chorioallantoic membrane model as a research tool and surgical simulator, for training with angiolytic lasers (Broadhurst *et al.*, 2007). Management of early glottic cancer with angiolytic laser has some useful translational characteristics:

- Surgeons can adopt this pulsed-angiolytic treatment of glottic cancer in a gradual manner. Similar to Lynch in 1920, they can initially select favourable lesions notable for small size, superficial invasion and central location in the rima glottidis, advancing to more extensive lesions in an individualised pace.
- Since a planned second-look procedure is a mandate, it is reasonable and expected to have limited residual cancer, which will be treated in the second-stage intervention. As already mentioned, staged intervention cannot have any deleterious effect on the outcome, since glottic cancer rarely metastatises. Furthermore, staged intervention is an entirely accepted modality for RXT.
- A novice need not be worried about the lack of expertise since second look is mandatory and therefore, single-surgery perfection is not necessary – there is substantially less pressure on the surgeon. This allows for a responsible learning curve without jeopardising successful patient outcome.
- After initial treatment, it is easy to identify early local failure in the office with video stroboscopy using telescopic and distal-chip flexible laryngoscopic technology so that prompt retreatment can ensue.

As a reassuring example, one of our cases showed recurrence at 18 months. She did not sustain vocal deterioration from the second laser treatment and is now more than two years in to follow up, without further recurrence.

10.7. Evaluation of angiolytic treatment for glottic cancer

To our knowledge, treating early glottic cancer with the angiolytic lasers is the first demonstration of employing non-ionising radiation without chemical enhancement (*e.g.*, photosensitising agents) to involute a malignancy without resection or gross ablation. Despite the fact that this is a recent innovation, we have employed this approach in over 100 cases (T1, T2) with ~95% control rate with the largest majority having over two years follow up.

11. Future considerations

Selectively ablation of intralesional/sublesional tumour vascularity with laser photoangiolytic treatment is a laudable goal. For example, *induction* light treatment could be applied at the time of staging endos-

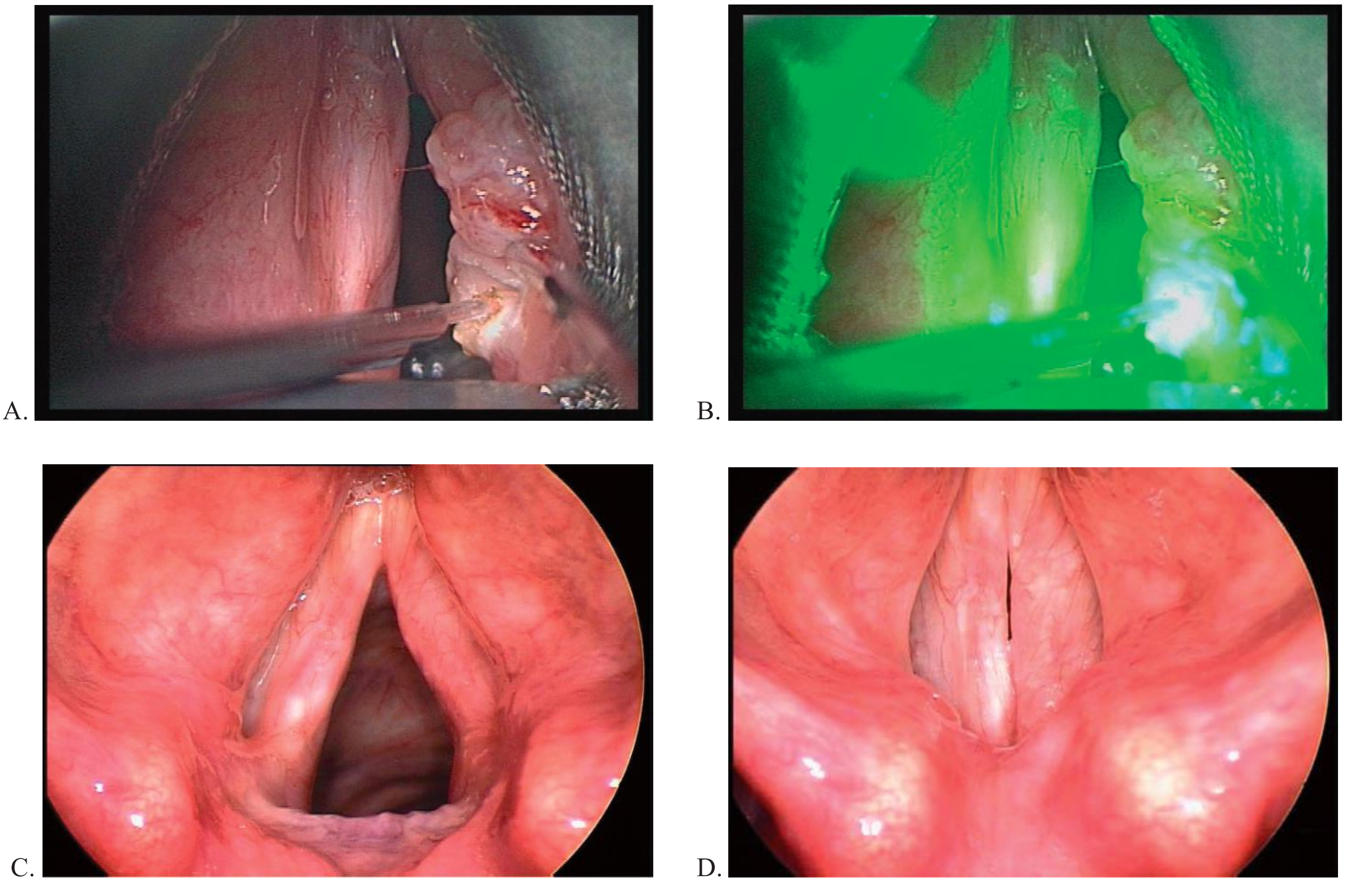

Fig. 8. T1N0M0 SCCA of the right vocal fold. The disease is attached to the perichondrium of the vocal process. Anteriorly, the disease extends into the superficial lamina propria but does not completely replace it by attaching to the vocal ligament. A. The laser fibre is directed at the tumour. B. The same view demonstrating the green light associated with 532 nm during a 15-ms pulse width. C. Postoperatively, on abduction, there is no evidence of persistent or recurrent cancer. Note that there is a slight excavated contour change in the region of the right vocal process due to treatment of the tumour in that location. In turn, this creates a slight convexity to the glottal aperture where superficial lamina propria has been preserved towards the center of the vocal fold. D. During adduction there is excellent glottal closure.

copy. Given the migration of many surgical interventions to be minimally-invasive and/or office procedures, these prospects are not inconceivable.

Based on our experience of managing epithelial cancer at the glottal site, in is entirely plausible that this concept be extended to other sites such as bladder, gut, tracheobronchial tree and the cervix. The multi-disciplinary use will justify the large capital outlay for its multi-centre evaluation.

12. Risk and benefit issues

We generally do not support office-based 585-nm PDL treatment of varices and ectasias since these lesions are highly susceptible to extravasation of blood into the SLP due to frequent vessel-wall rupture. (Zeitels, 2006b; Broadhurst *et al.*, 2007a; 2007b) This predisposes the indiscriminate absorption of the 585-nm irradiation into blood-stained and otherwise normal superficial lamina propria. We have witnessed permanent scarring and dysphonia in vocalists after PDL treatment from another institution, due to photothermal trauma to the delicate pliable layered microstructure of glottal mucosa, both to the SLP and to the overlying epithelium.

Furthermore, using a short pulse-width angiolytic laser 585-nm PDL on hemorrhagic polyp of vocal fold will often destabilise the normal overlying epithelium due to the volume of blood within the lesion that preferentially absorbs the yellow light. This destabilisation of basement-membrane-zone linking proteins (Gray, 1994), while an asset for epithelial diseases such as dysplasia and papillomatosis, is a *liability* with phonotraumatic subepithelial lesions. Preservation of the overlying epithelium in treating benign superficial lamina propria lesions remains as a logical well-accepted key objective for optimising the postoperative pliability of phonatory mucosa and vocal function (Zeitels, 2001b; 2001c; 2002b).

Office-based angiolytic surgery should not be carried out in patients with laryngeal polyp that typically would be managed by a single phonomicrosurgical procedure. Planned staged subtotal treatment for these lesions in healthy patients can be philosophically problematic.

13. Discussion

Since the origin of laryngology in the 1800s, when office-based mirror-guided treatment was routine, the metric for success for surgeons has always been complete removal of the lesion along with voice improvement. Today, unlike in the nineteenth century, the surgeon performing office-based surgery is typically using video imaging for the procedure as part of the medical record. In turn, patients often expect to view the efficacy of the procedure. This transparency in demonstrating surgical success is implicit to the trust engendered in office-based management. In addition, many patients with phonotraumatic lesions have other structural deformities in addition to the visually conspicuous polyp and these deformities may be discernable by microlaryngoscopy and not office laryngoscopy.

Most surgeons principally treat glottal dysplasia and papilloma in the operating room under general anaesthesia. It provides diagnostic accuracy, better therapeutic precision leading to better functional outcome, and oncological control of the excised margin. However, there is an unavoidable morbidity associated with general anaesthesia and costs considerations are unavoidable. These factors may detract a planned, multi-stage procedure for optimum oncological and functional outcome. The driver for readmission may be recurrence of symptoms, airway compromise or visual outpatient assessment. All surgeons and patients inherently acknowledge the detractors associated with general anaesthesia in microlaryngoscopic treatment since they are required to develop an individualised plan for repeated treatment.

This current management approach in adult patients is based on pragmatic clinical factors that may not always align with optimal disease management and functional outcome. When these diseases occur in a more accessible region with less delicate function such as the oral cavity or skin, they are often treated more frequently under local anaesthesia. If a safe and efficient topical anaesthesia becomes available then the threshold for repeated laryngeal intervention will be lowered.

There is a perceived disadvantage of the local anaesthesia approach in that this treatment pathway may ultimately lead to more frequent procedures. This is mainly because the threshold for intervention is decreased commensurate with the diminished morbidity associated with local anaesthetic treatment. In addition, individual office-based operations are generally less effective as compared with operative procedures under general anaesthesia. The surgeon is understandably less aggressive using the angiolytic lasers with local anaesthesia due to reduced visual precision and the fact that the vocal folds are moving. It is our hope that with greater experience in this new treatment pathway, we will be able to more closely simulate the treatment capabilities that we achieve using general anaesthesia.

Angiolytic lasers have been incontrovertibly effective in treating papillomatosis and dysplasia without the associated clinically-observed soft-tissue complications such as superficial lamina propria scarring and anterior commissure web formation associated with the CO_2 laser due to thermal damage leading to tissue necrosis (Franco *et al.*, 2002; 2003; Zeitels *et al.*, 2004). Based on the experience of treating over one thousand cases with angiolytic lasers, the author believes that the science of angiolytic laser is a seminal platform for the development of a number of applications for surface mucosal lesions (*e.g.*, Barrett's oesophagus, dysplasia of the cervix, granulation in the nose and ear). However, in the medical field, any new technology is slow to make inroads for a variety of reasons. When the new technique could potentially replace existing methods of management, it is referred to as a *conflicting* technology (Christensen, 1997). There are a number of factors and forces that may mitigate and/or block the adoption of a valid new technique or technology (Zeitels, 2007c).

Despite the fact that office-based procedures are more time efficient and can be more remunerative than phonomicrosurgery, surgeons should employ discerning judgment. Embarking on repeated office treatments for some vocal lesions may send a problematic message to the patient and other surgeons. We recently have had patients come to our facility inquiring as to why their repeated office PDL 'scar-softening' procedures had not improved their voice.

These individuals were under the impression that this procedure was a standard treatment strategy; however, we are unaware of peer-reviewed research that suggests that mucosal pliability can be *restored* by angiolytic laser irradiation. These patients are sometimes desperate and often highly motivated and impressionable so that they are often willing to embark on unorthodox pathways. Vigilant well-explained informed consent is an important responsibility when suggesting unproven novel surgical interventions to patients with phonatory mucosal scarring.

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MCQ – 60. Angiolytic lasers in the management of benign and malignant laryngeal disease and the establishment of office-based laryngeal laser surgery

1. The term angiolytic laser is used for
    - a. Lasers which vaporise the blood vessels
    - b. Lasers with properties of selective photothermolysis
    - c. Lasers which destroy the blood vessels by rupturing
    - d. Lasers which coagulate the blood but keep the vessel wall intact
    - e. Lasers which cause haemostasis to minimise bleeding during ablation

2. Commonly used angiolytic lasers emit at
    - a. 10,600 nm
    - b. 585 nm
    - c. 2.1nm
    - d. 810 nm
    - e. 532 nm

3. Angiolytic lasers are suitable for
    - a. Early glottic cancers
    - b. Papillomatosis
    - c. Singers nodes
    - d. Reinke's oedema
    - e. Ectasias

4. The effect of angiolytic lasers is due to
    - a. Deprivation of blood supply by causing dehiscence in the blood vessel
    - *b.* *Selective* photothermolysis of the sub-epithelial microvasculature
    - c. Vaporisation of micro-vessels within the lesion
    - d. Avascular tissue destruction
    - e. Ischaemia of diseased epithelium

5. Angiolytic laser energy
    - a. Is strongly absorbed by haemoglobin in the blood
    - b. Is strongly absorbed by plasma
    - c. Causes tumour to involute due to avascular necrosis
    - d. Results in thermal damage of intralesional blood vessels
    - e. Results in coagulation of the contents of the blood vessel

6. Angiolytic effect as against ablation effect is dependent upon
    - a. The wavelength used
    - b. The target to tip distance
    - c. The nature of targeted microvasculature
    - d. The energy setting of each pulse
    - e. All of the above

7. The angiolytic effect can include
    - a. Involution of the tumour tissue due to deprivation of blood supply
    - b. Ablation of the tumour tissue due to thermal damage

   c. Sparing of thermal damage of the surrounding normal tissue when treating superficial mucosal lesions
   d. Preservation of the superficial lamina propria when treating mucosal lesions with angiolytic lasers
   e. All of the above

8. Pulse dye laser
   a. The pulse width is not adjustable
   b. The pulse width is adjustable but cannot be reduced sufficiently to prevent heating the wall of the vessel
   c. Is strongly absorbed by the wall of the blood vessel causing it to rupture
   d. Is maintenance free and does not need calibration
   e. Energy cannot be accurately controlled to effect coagulation of blood without causing rupture of vessel wall

9. The KTP laser
   a. Exposure to microvasculature causes photothermolysis
   b. Photothermolysis effect is possible only when *pulsed* KTP laser is used
   c. In pulsed KTP laser, it is not possible to adjust the pulse width and hence absorption of the energy by the wall of the blood vessel may result in extravasation of blood
   d. Photothermolysis of the blood vessel involves its ablation due to vaporisation
   e. Energy can be delivered through 300 µm to 600 µm fibres

10. Office-based laryngeal surgery has certain limitations
   a. The patient co-operation is necessary
   b. A good topical anaesthesia is necessary
   c. An experience in using a laser on a moving target such as the vocal fold is necessary
   d. If the blood extravasates, then the laser energy will be absorbed by extravasated blood and result in thermal damage of the tissue in which the blood has extravasated
   e. All of the above

11. Office-based procedure is not optimal in patients
   a. With a pathology requiring several episodes of surgery to effect complete cure
   b. With medially facing pathology since the laser will strike tangentially
   c. Who require precision phonosurgery to optimise preservation of voice
   d. Where procedure is expected to last more than 30 minutes
   e. Who are in the Elderly patient group

12. Office based surgery with angiolytic laser is indicated in
   a. Removal of polyp from vocal fold
   b. Removal of nodule from vocal fold
   c. Cancer of vocal fold invading paraglottic space
   d. Ectasia causing frequent bleeding who are not candidates for general anesthesia
   e. Frequently recurring dysplasia (Vasant: Dysplasia and RRP comprise >95% of the patients)

13. Anti-angiogenic treatment is
   a. A complimentary treatment to the use of angiolytic laser
   b. Given orally in selected cases
   c. Is injected sub-lesionally
   d. is injected in to the diseased vocal fold
   e. Is given to discourage neovascularisation

14. Angiolytic laser treatment for early cancers of the vocal fold
    a. Consists of vaporisation of the superficial tumour tissue by heating the intralesional microcirculation and then and then treating the sublesional microvasculature at the tumour margin in a pulsed mode
    b. Consists of exposure primarily of the intralesional microvasculature so that the tumour tissue deprived of blood supply involutes
    c. Results in partial involution of tumour and therefore a risk of metastatic spread
    d. Involving anterior commissure is contraindicated since it results in web formation
    e. As a staged procedure is appropriate when disease is in the internal aspect of the anterior commissure and is likened to similar protocol when such cancers are treated with a course of RXT

Chapter 61

Basic science of laser cartilage reshaping

A. Foulad, D.E. Protsenko and B.J.F. Wong

1. Introduction

Cartilage is a dense and flexible connective tissue that is composed of chondroctyes surrounded by an extracellular matrix. The extracellular matrix largely contains water, collagen type II, and proteoglycans. In its native state, the negatively charged proteoglycans promote the influx of positively charged counter ions such as Na^+ and Ca^{2+} in order to maintain electrical neutrality. This generates a relatively high osmolarity within the matrix that facilitates the inward flow of water. The resulting expansive forces are counteracted by the collagen fibre network and the cartilage maintains a stable turgid state. This dynamic equilibrium, in addition to the electrostatic repulsion forces between the negatively charged proteoglycans, provides the inherent forces necessary to resist compressive and tensile deformation.

The ability to overcome the elasticity and shape memory properties of cartilage in order to yield permanent shape change is an important element of facial reconstruction. The correction of cartilaginous deformities is often required to restore traumatic, oncologic, and congenital malformations to their normal anatomical configuration. Traditional cartilage reshaping methods include cutting, scoring, suturing, and morselising. In comparison to these surgical techniques, laser cartilage reshaping (LCR) is advantageous because it does not necessarily require cutting the skin or mucosa and is associated with spatially limited injury of the cartilage.

Laser cartilage reshaping typically follows a general procedure as illustrated in Figure 1. The cartilage is first deformed to the desired shape using a jig, which consequently produces stress in the regions of applied force. These areas of stress are irradiated using laser energy in order to induce mechanical relaxation and thus minimise the inherent forces within the cartilage that resist the new configuration.

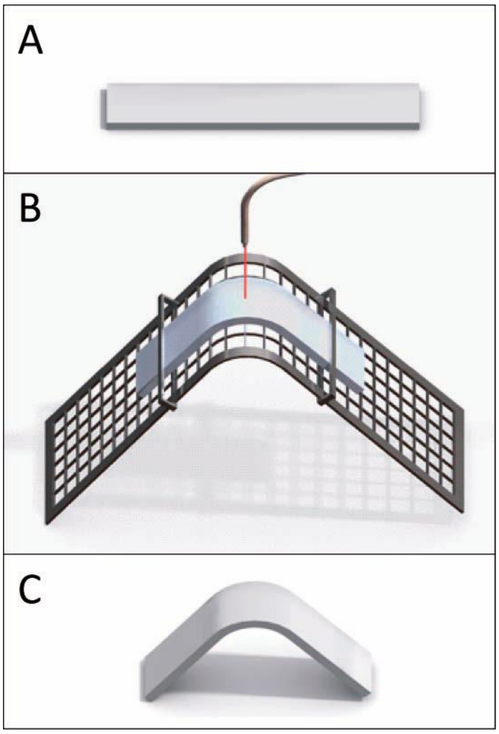

Fig. 1. General LCR procedure. Native cartilage (A) is deformed into a new shape and the regions with increased stress are irradiated (B). This results in permanent shape change of the cartilage (C).

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After a period, the jig is removed and the new shape is maintained. For reshaping procedures that involve irradiation through intact skin or mucosa, cooling adjuncts are employed to protect the overlying superficial tissues from thermal damage (Karamzadeh *et al.*, 2001; Mordon *et al.*, 2004; Chang *et al.*, 2008).

2. Background

Laser cartilage reshaping was first proposed by Emil Sobol in 1992, who viewed cartilage from the perspective of the material scientist and hypothesised that cartilage has properties that are similar to man-made polymers and plastics which, in industry, are exposed to heat to thermoform unique and complex geometries. During a sabbatical in Crete, Sobol worked with Emmanuel Helidonis and successfully demonstrated the concept of cartilage thermoforming in an ex vivo animal model (Helidonis *et al.*, 1993) and subsequently in *ex-vivo* human septum (Sobol *et al.*, 1994).

3. Various hypotheses for laser cartilage reshaping

3.1. A therapeutic window for laser heating

Sobol hypothesised the existence of a *privileged* set of laser dosimetry parameters that provided a therapeutic window for stress relaxation and shape change, but without significant thermal injury to either the matrix or the cells (Sobol *et al.*, 1996b). He theorised that thermally mediated effective cartilage reshaping coincides with a temperature transition of approximately 70 °C (Sobol *et al.*, 1994; Sobol *et al.*, 1996a).

3.2. Spatially selective heating

Although numerous studies have confirmed the necessity of reaching a temperature threshold near 70°C to attain adequate stress relaxation, there is growing evidence to suggest that shape change is obtained at the expense of tissue viability (Karamzadeh *et al.*, 2005; Wright *et al.*, 2005; Karam *et al.*, 2006; Li *et al.*, 2007). Accordingly, LCR can be attributed to the concept of spatially selective heating in which cell viability is affected in an optimised pattern. Lasers provide the ability to precisely control and target heating at regions of concentrated stress and thus minimise the extent of tissue damage.

3.3. Phase transition

Early on, Sobol hypothesised that the mechanism of LCR is largely due to the redistribution of water within the cartilage tissue via a 'bound-to-free water transition' (Sobol *et al.*, 1994, 1996a). According to this concept, water bound by proteoglycan anions is released and replaced by cations during LCR. The binding of cations subsequently neutralises the repulsion forces between the negatively charged proteoglycans and stabilises the new shape of the cartilage tissue. Sobol demonstrated that, once a temperature of 70°C is reached during irradiation of a cartilage specimen, the following changes take place:

- There is a decrease in internal stress
- A momentary temperature plateau is reached, during which temperature no longer rises
- A peak in energy occurs, detected via calorimetry
- There is a change in light scattering (Sobol *et al.*, 1997)

He felt these findings were characteristic indicators of the temperature dependent, bound-to-free water transition.

Numerous other studies have further investigated the optical, mechanical, and thermodynamic properties of cartilage during laser irradiation, with similar results (Bagratashvili *et al.*, 1997; Chew *et al.*, 1998; Sviridov *et al.*, 1998; Wong *et al.*, 1998b,c; 1999b; Chae *et al.*, 2001; 2002; 2003; Viktor *et al.*, 2001; Omel'chenko and Sobol, 2008).

3.4. Collagen denaturation

Several additional mechanisms for LCR have been hypothesised, including collagen denaturation and breaking of weak non-covalent bonds (Sobol *et al.*, 2000a). Thermal denaturation of collagen requires an activation energy that is sufficient to break hydrogen bonds and unfold the collagen triple helix (Luescher *et al.*, 1974). There is evidence to support that the temperature elevations associated with LCR are likely to be associated with some degree of irreversible collagen denaturation (Kuo *et al.*, 2000). However, non-destructive collagen modification and reorganised of the proteoglycan framework has been supported by the results of spectroscopic analysis (Ignatieva *et al.*, 2007) and also by evidence of the preservation of immunoreactivity to collagen type II idiotopes (unique set of antigenic determinants) after heating (Holden *et al.*, 2009b).

3.5. Formation of micropores

Scanning force microscopy revealed formation of micropores (Sobol *et al.*, 2000b), which may possibly facilitate shape change by separation of proteoglycan or chondroitin sulfate from the hyaluronic backbone and protein core respectively.

3.6. Formation of crystals

There is also evidence of sodium bicarbonate crystal formation in irradiated cartilage, though these crystals have a short life and, probably, do not have a role in long-term shape change. In contrast, the formation of more stable calcium sulfate and calcium phosphate crystals have been identified in irradiated cartilage specimens (Heger *et al.*, 2006).

4. Shape change

4.1. Ex-vivo shape change

4.1.1. Animal model

Early work with LCR was performed primarily through the use of *ex-vivo* tissues obtained from the auricular and nasal septal cartilages of rabbits and pigs. The selection of these animal models was made on practical grounds as these tissues are readily available in bulk quantities and at a low economic cost. In particular, rabbit septal cartilage is favourable in contrast to porcine tissue because it is consistently uniform in shape, size, and composition from animal to animal. However, neither rabbit nor pig septal cartilages truly mimic the composition and dimensions of their human counterparts. There is minimal literature regarding the use of *ex-vivo* human tissue because viable human septal and auricular cartilage is rarely available and specimens are generally small surgical bits.

4.1.2. Choice of lasers

The first study to demonstrate non-ablative laser cartilage reshaping within the head and neck utilised a CO_2 laser (λ = 1060 nm) to reshape *ex-vivo* rabbit ear cartilage (Helidonis *et al.*, 1993). Subsequently, a long-term study concluded that similarly reshaped cartilage specimens retained their shape one year later (Velegrakis *et al.*, 1994). Although these studies successfully demonstrated the feasibility of LCR, the use of a CO_2 laser is not ideal because of its shallow penetration depth. Although increasing laser power and exposure time can potentially extend the elevated temperature field to a greater depth via conductive heating, there is a trade off. There is excessive heating, carbonisation, ablation, and increased injury at the surface of the tissue. The disadvantages of the CO_2 laser lead the way to using better-suited lasers with greater penetration depths for LCR studies. These include the Nd:YAG (λ = 1320 nm), Nd:YAG (λ = 1440 nm), diode (λ = 1450 nm), Er: Glass (λ = 1540 nm), Ho:YAG (λ = 2100 nm), and Er:YAG (λ = 2940 nm) lasers.

An ideal laser wavelength corresponds with a penetration depth that is similar to the full or partial thickness of the cartilage required to be heated depending upon the application. The penetration depth of the light is dependent upon the optical properties of the target tissue, and can be estimated given parameters of the absorption and reduced scattering coefficients of the target tissue. In cartilage, these coefficients have been previously measured by Youn *et al.* (2000) using porcine tissue.

Penetration depth (δ) is inversely correlated to both absorption (μ_a) and reduced scattering (μ_s) and can be roughly estimated using the equation referenced by Welch and Van Gemert (1995). Accordingly, the commonly used 1320 nm and 1540 nm wavelength lasers have an approximate penetration depth of 2.8 mm and 0.8 mm, respectively. To more precisely characterise penetration depth, we have performed Monte-Carlo simulations that demonstrate the fluence rate distribution along the axis of the laser beam for several commonly used laser wavelengths (Fig. 2). The simulations were performed for

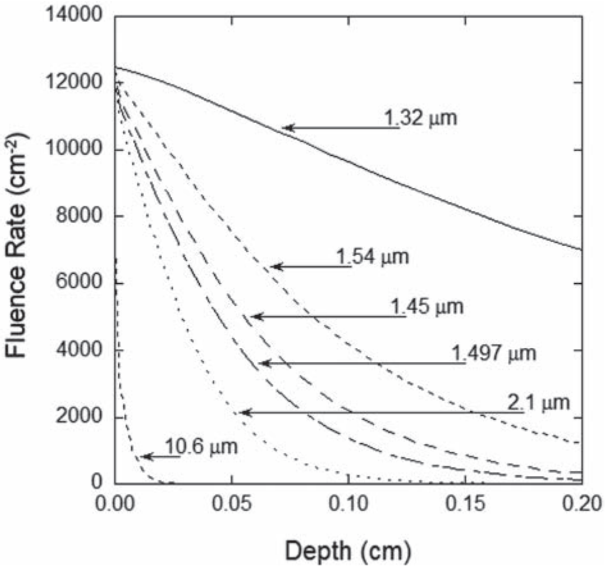

Fig. 2. Numerical estimation of fluence rate as a function of depth for several laser sources used in LCR studies.

a collimated point source using code described by Wang *et al.* (1995a).

4.1.3. Laser dosimetry

A detailed study of quantitative shape change and an objective assessment of shape retention after LCR as a function of dosimetry were first demonstrated by Wong's group (Gray *et al.*, 2001; Wright *et al.*, 2005). They reshaped flat porcine and rabbit septal cartilage specimens into a semicircle and described the resulting shape using a single numerical solution. Although clinically relevant dosimetry settings were used, the cartilage specimens only partially retained their new shape. Hence, the cartilage had shape memory which was not completely overcome by LCR.

Numerous studies have examined the impact of laser dosimetry on shape change and have clearly shown that the degree of shape retention directly correlates with the total energy delivered. However, in order to minimise cell injury, laser dosimetry should be limited to achieving mechanical relaxation at the critical transition of approximately 70°C. Consequently, it may be necessary to compensate for the slight reversion in shape change by over-correcting the cartilage during irradiation, or by splinting the tissue and allowing native wound healing responses to aid in the reshaping process.

4.1.4. Prevention of costal cartilage warping

Another use of LCR is the rapid stabilisation of the warping process in grafts obtained from the peripheral regions of costal (rib) cartilage. Traditionally, surgeons prefer to harvest costal cartilage grafts from the central core of rib because grafts obtained from more peripheral regions warp over a period of hours to days (Gillies, 1920; Gibson and Davis, 1957; Adams *et al.*, 1999). It has recently been demonstrated that laser irradiation of peripherally obtained porcine costal cartilage grafts accelerates stress relaxation and rapidly stabilises shape change within 30 minutes (Foulad *et al.*, 2010).

4.1.5. *In-vivo* shape change

Several *in-vivo* studies have investigated laser cartilage reshaping of the ears using animal models. The first notable study was performed by Jones *et al.* (2001) using a Ho:YAG ($\lambda = 2100$ nm) laser to reshape pig ears. Although they examined several laser exposure treatments that varied from minimal effect to obvious cartilage necrosis, none of the experimental ears retained their shape longer than three weeks. Recognising that shape reversion was likely to be due to a shallow penetration depth, Mordon *et al.* (2004) subsequently performed a study that used a deeper penetrating Er:Glass ($\lambda = 1540$ nm) laser to reshape rabbit ears. In addition, they utilised contact cooling during irradiation in order to minimise superficial temperature elevations and prevent skin injury. The shape had stabilised at ten days, and was retained at the end of the six-week study in the majority of specimens. Holden *et al.* (2009a) performed a similar experiment to reshape a thicker region of the rabbit ear that better matches the thickness of its human counterpart. They used a 1450-nm diode laser, combined with cryogen skin cooling. The ears which were splinted in the desired shape for a longer period after irradiation were stiffer and had more pronounced shape change. Significant shape retention was observed for all experimental specimens up to the end of the 4-week study.

Reshaping of canine tracheal cartilage in vivo has been successfully performed by Wang *et al.* (1995b; 1996) in an effort to develop technology to correct tracheal and subglottic stenosis. In these experiments, anterior tracheal wall collapse was repaired using a Nd:YAG ($\lambda = 1440$ nm) laser. After six weeks, the airway improved significantly, was lined by healthy mucosa and demonstrated acceptable resistance to external force.

5. Mechanical stability

The underlying principle of LCR is that focal heating of cartilage leads to mechanical relaxation. Assuming a homogenous isotropic cartilage structure that is reshaped into a relatively simple geometry, the change in the stiffness of the cartilage can be described by the measurement of Young's modulus. A low Young's modulus indicates that the tissue is relatively less stiff and a small pressure is sufficient to deform it. Several studies were performed for measurement of Young's modulus before, during, and after LCR in rabbit (Chao *et al.*, 2003) and pig (Gaon *et al.*, 2003) septal cartilage. The results demonstrated that the Young's modulus decreases during and immediately after irradiation, and that increased laser exposure results in progressively greater softening. After rehydration in saline, the Young's modulus of the cartilage specimen returned to approximately 90% of the pre-irradiation value. Work by El-Tayeb *et al.* (2007) resulted in similar findings for rabbit auricular cartilage and confirms that the

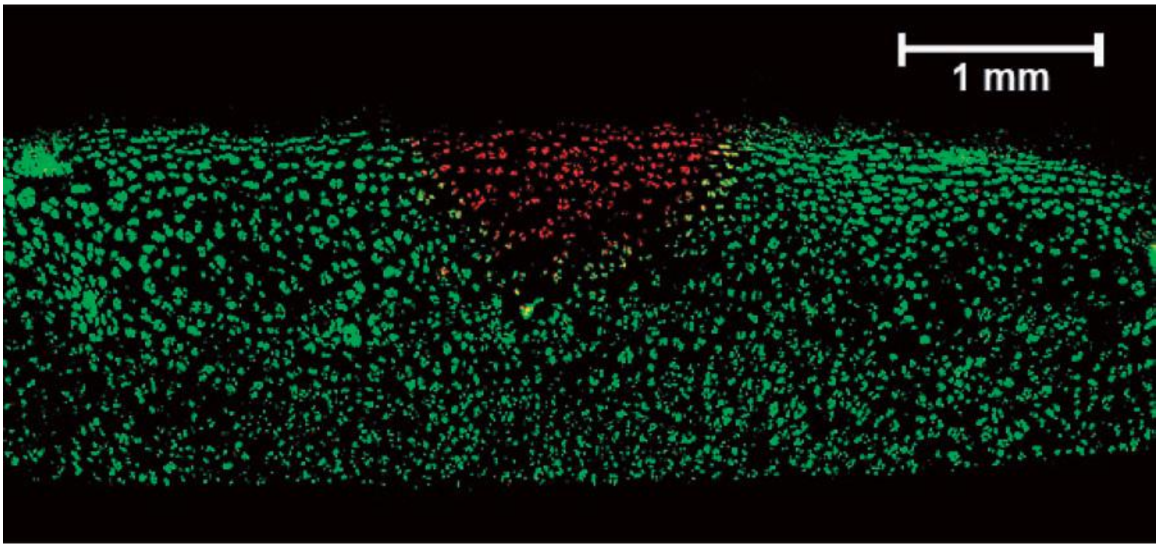

Fig. 3. Fluorescent confocal imaging of a cartilage cross section after laser irradiation. The red region indicates cell death.

softening of cartilage is only transient and that reshaped specimens maintain mechanical properties very similar to their native counterparts.

6. Viability

Early viability studies utilised traditional histological staining to visualise the structure of cartilage using light and electron microscopy. Using these techniques, Velegrakis *et al*. (1994) observed minimal destructive changes in cartilage after LCR and concluded that the chondrocytes remained viable. Sviridov *et al*. (1998) further confirmed these results and proposed that focal cytoplasmic vacuolation is associated with reversible cell injury whereas nuclear condensation is associated with cell death. However, these histological findings are extremely subtle and can be difficult and controversial to interpret. An additional limitation of conventional histology is that tissue fixation results in dehydration of the chondrocytes which leads to an inadequate representation of the tissue.

Fluorescent live/dead assay staining overcomes the shortcomings of conventional light microscopy and is recognised as a more accurate, reliable, and superior method to analyse viability. Prior to its adaptation for use in LCR, the live/dead assay system was used extensively in orthopaedic applications to evaluate radiofrequency-induced thermal injury in articular cartilage. The dyes used in this assay system preferentially target cells based on membrane integrity and functional enzymes. Live cells emit green fluorescence and dead cells emit red fluorescence. Initially, the live/dead fluorescent assay was combined with flow cytometry in order to examine large populations of individual cartilage cells after LCR. This technique detected that only about 60% of the chondrocytes from irradiated regions remained viable after LCR and that viability further decreased with additional exposure times (Rasouli *et al*., 2003). These results were in accordance with prior work that assessed viability by examining proteoglycan synthesis rates (Wong *et al*., 2000). In addition, live/dead assay and flow cytometry have been used to estimate the Arrhenius rate process coefficients that predict thermal injury following laser heating (Diaz *et al*., 2003).

In order to visualise the distribution of live and dead chondrocytes in tissue, the live/dead assay system has been used in conjunction with confocal microscopy. Cross-sectional confocal images of cartilage obtained shortly after LCR demonstrate a clearly demarcated red region of cell death at the laser site (Fig. 3). As laser dosimetry is increased, the width and the depth of the injured region also increase. This imaging modality has been used to examine cartilage after LCR in both animal and human tissues for a broad range of laser wavelengths and dosimetry parameters (Karam *et al*., 2006; Li *et al*., 2007; Choi *et al*., 2008; Holden *et al*., 2009a).

Regions of acute thermal injury after LCR are followed by a certain degree of repair and chondrocyte proliferation *in vivo*. Mordon and colleagues (2004) have effectively demonstrated this concept by using an immunohistochemical approach to ex-

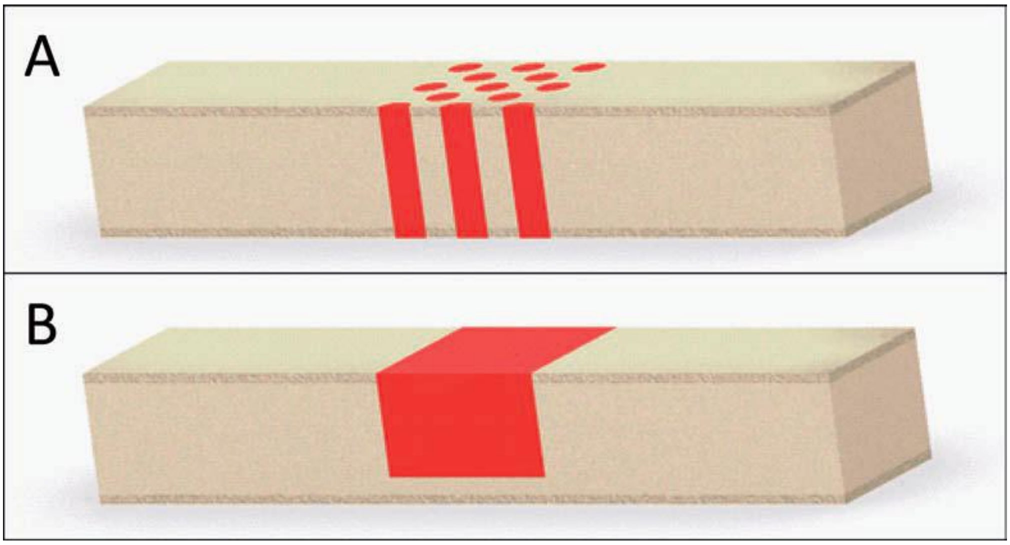

Fig. 4. Spatially selective heating can be performed using a lateral (A) or axial (B) approach.

amine reshaped auricular cartilage in an in-vivo rabbit model. They used anti-proliferating cell nuclear antigen (PCNA) to identify proliferating chondrocytes and, as a supplement, used haematoxylin-erythrosin-safran (HES) to identify cell structure. During the first few weeks after irradiation, they observed chondroblastic proliferation near the stem cell rich perichondrium. It has been hypothesised that this reparative process is stimulated through the thermal effects of laser irradiation and differs from the typical wound healing response. The expression of collagen type I, which is typical of scar formation, has been shown to be absent after LCR (Holden *et al.*, 2009b). Instead, there is evidence of normal cartilage matrix development through the increased expression of collagen type II. The viability studies performed on cartilage after LCR highlight the importance of dosimetry optimisation and spatially selective heating. Considering that increased irradiation exposure leads to reduced cell viability, it is essential to limit focal heating to the minimum required to attain clinically relevant shape change. However, tissue injury is not entirely avoidable and should be spatially scattered within regions of healthy tissue, such as in a checkerboard pattern (Fig. 4A). Alternatively, the irradiation can be limited axially so that the entire full thickness of the cartilage is not thermally altered (Fig. 4B). Both these methods preserve nearby viable perichondrium and matrix that can aid in reparative processes.

7. Feedback control

Investigations aiming to determine the mechanism of LCR have identified characteristic alterations in the biophysical properties of cartilage that are associated with temperature-dependent stress relaxation. These studies have lead to the development of non-invasive techniques to monitor the reshaping process and provide real-time signals for terminating laser irradiation. However, there is currently less interest in feedback control because dosimetry settings to achieve shape change are now well defined. This knowledge allows lasers to be effectively used in an open-loop fashion similar to dermatologic laser procedures, but feedback may be beneficial to provide for greater optimisation or as an automatic backup safety alarm.

A surface temperature of approximately 70°C is among the more simple measurements that can be obtained as a signal for stress relaxation and adequate laser exposure during reshaping. A caveat of this approach is that the exclusive monitoring of surface temperature is unreliable when surface cooling is used as an adjunct to minimise superficial tissue damage. A method to monitor stress relaxation independently of surface temperature includes exposing cartilage to light from a probe during reshaping and monitoring the integrated back-scattered light (Wong *et al.*, 1997; 1998a). Consideration must be placed on the probe's wavelength for precise feedback measurements (Basu *et al.*, 2001). In addition, polarisation-sensitive optical coherence tomography (PSOCT) has been demonstrated to detect a decrease in phase retardation after irradiation and might provide additional feedback data (Youn *et al*., 2001; Youn *et al*., 2005).

Furthermore, monitoring photoacoustic signals that are generated as a by-product of laser heating provides signals indicating the attainment of stress relaxation (Omel'chenko *et al*., 2000). This has lead to the examination of using ultrasound for feedback control (Carbone *et al*., 2005). Prototype feedback control devices have been developed and described (Wong *et al*., 1999a; Burden *et al*., 2001) and a clinical feedback device has been successfully used to reshape human nasal septum (Sobol *et al*., 2010).

7.1. Numerical modelling

The formulation of mathematical models that describe and predict the effect of laser irradiation on cartilage facilitates the optimisation of the LCR process. During the beginning of LCR, Sobol developed a theoretical model that aids in the calculation of the temperature fields associated with laser irradiation (Sobol and Kitai, 1998). Subsequently, Wong's group has investigated the thermal, optical, and mechanical properties of cartilage in order to further develop a comprehensive set of numerical models. Initially, they formulated a finite-element model that predicts the distribution of temperature in cartilage as a response to laser irradiation (Diaz *et al*., 2001). This detailed model takes into account the transformation of laser light to thermal energy, heat conduction, and water evaporation. An additional model incorporates the Arrhenius equation to predict cell injury as a function of heat (Diaz *et al*., 2003). Lastly, a numerical model has been developed for nasal septum reshaping that describes the effect of the number, location, and size of irradiation sites on stress relaxation (Protsenko and Wong, 2007). This model was subsequently enhanced by accounting for the nonuniform temperature distributions caused by the attenuation of laser energy by cartilage tissue both laterally and axially (Protsenko *et al*., 2008).

8. Clinical applications

Chapters 62 and 63 describe the clinical applications of laser cartilage reshaping for deviated nasal septum and protruding pinna. Below is a brief summary.

8.1. Nasal septal cartilage reshaping

8.1.1. Method

The current literature describing laser cartilage reshaping of human nasal septal cartilage is based on clinical procedures performed in Russia and Greece (Ovchinnikov *et al*., 2002; Bourolias *et al*., 2008; Sobol *et al*., 2010). Septal cartilage reshaping is performed using topical anaesthetics within an office-based setting. A physical deforming force, such as from a speculum or septal elevator, is applied to the septum to straighten the deviation. The septum is then irradiated, typically with an Erbium-doped glass fibre laser, through the mucosa at regions of concentrated internal stress. A feedback-controlled monitoring system equipped with an optoacoustic sensor has been used in the majority of reported cases, however this is not conditional, since dosimetry parameters are well-defined. After irradiation is complete, the deforming force is removed and packing is placed in the nasal cavity to splint the nose for a short period.

8.1.2. Selection of patients

Selection of patients requires identification of the appropriate septal defect geometry that is amenable to the minimally invasive technique of LCR. Significant structural deformities such as septal spurs, frank fractures, and acute 90° bends do not lend themselves to the conservative method of laser reshaping and are better suited for conventional procedures. Ideal patients have septal deviations that are curvilinear, such as Mladina's classification type 1 through 3 (Mladina, 1987).

8.1.3. Outcome

Several hundred patients with septal deviations have undergone this minimally invasive procedure since 1998 with encouraging results. A majority of the patients have reported improvements in symptoms during a two-year follow-up period. In addition, rhinomanometry analysis demonstrates equally positive results (Ovchinnikov *et al*., 2002). However, no studies have performed comprehensive before-and-after analysis using more definite means such as computed tomography, magnetic resonance imaging, acoustic rhinometry, or functional nasal airway modelling. Since the initial clinical trials, the reshaping technique has been refined and a laser device has been manufactured.

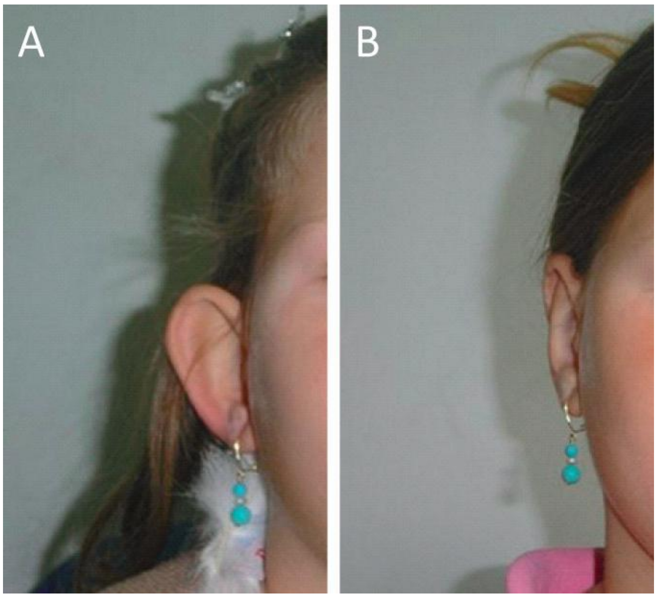

Fig. 5. Patient before (A) and three months after (B) correction of prominent ear using LCR. (Courtesy of Serge Mordon, Lille University Hospital, Lille, France.)

8.2. Auricular cartilage reshaping

Laser cartilage reshaping of the human pinna has been successfully performed by Mordon's group (Trelles and Mordon, 2006; Leclere *et al*., 2010). They corrected protruding ears by creating an adequate antihelical fold and concho-mastoid angle (Fig. 5). Their case series now measures over 30, with striking results demonstrated by photographs of several cases.

In their most recent study, they used a Er:Glass (λ = 1540 nm) laser with integrated contact cooling. The entire helix and concha were irradiated on both sides using a cumulative fluence of 84 J/cm^2 via seven stacked pulses and a 4-mm spot size. Additionally, a group of patients received a lower cumulative fluence of 70 J/cm^2. The ear was then manually deformed into the desired shape while a silicone elastomer was allowed to harden within the ear. Patients kept the mould in their ear for three weeks at all times, followed by three weeks only at nights. The majority of patients had excellent and stable results after one year. The patients with less than ideal results were found to have an improperly formed mould or were part of the group that received a lower cumulative fluence.

9. Conclusion

LCR remains an emerging clinical technology, but holds great promise as it may convert a wide range of classic surgical operations to simple office-based procedures and profoundly reduce health care costs and patient morbidity. Although the mechanism is not completely understood and the procedure is not yet fully optimised, several clinical studies using LCR to correct septal deviations and prominent ears have demonstrated dramatic results. Future research will focus on broader clinical implementation and device development in tandem with basic studies focused on mechanisms of action.

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MCQ – 61. Basic science of laser cartilage reshaping

1. Laser cartilage reshaping (LCR)
    a. Requires minimum incision on the mucosa /skin
    b. Requires a specific wavelength laser to get optimum results
    c. Does not require a specific wavelength and most lasers used in ENT clinical practice can be used for LCR provided correct dosimetry is used
    d. Is based on shrivelling the cartilage with laser thermal energy, reshaping it and maintain the new shape with a mould
    e. Is based on using laser energy to induce mechanical relaxation and minimise the inherent forces within the cartilage that resist the new configuration

2. The new shape is obtained
    a. At the expense of tissue viability
    b. By optimising tissue viability and minimising tissue damage
    c. By overcoming the elasticity and shape memory properties of cartilage
    d. By initial scoring to achieve the new shape followed by laser exposure
    e. By using a jig to mechanically create new shape followed by laser exposure

3. The laser wavelength suitable for cartilage reshaping
    a. Should have maximum absorption at the point of stress in the cartilage to relax it so that new shape can be formed easily
    b. Should have a uniform depth of penetration for the whole thickness of the cartilage so that the new shape can be formed easily
    c. Should have a minimum scatter
    d. Should be fibre transmissible
    e. Is Erbium doped glass fibre laser emitting at 1540 nm

4. The key factor is the temperature rise with the laser exposure. At 70^0C
    a. The heat distribution is even both spatially and axially
    b. There is a temperature gradient most suitable for reshaping the cartilage
    c. A privileged set of laser parameters that provides a therapeutic window
    d. It provides a state of static window which relaxes stress and allows new shape to be formed
    e. There is no significant thermal injury to either the matrix or the cells

Chapter 62

Clinical application of laser cartilage reshaping for deviated nasal septum

F.M. Leclère, I. Petropoulos, M. Trelles and S.R. Mordon

1. Introduction

Nasal obstruction is the most common rhinological complaint. Its aetiology is multi-factorial, with a prevalence of up to one-third of the population (Bateman *et al*., 2003). This high prevalence, and its associated social and economic implications, makes the management of this condition of great interest. Short-term medical management, usually prescribed by the primary physician, consists of topical decongestants in the form of sprays or drops. Systemic decongestants and antihistamines are also prescribed. Topical steroids are given if there is evidence of polypi.

If short-term medical therapy fails to provide long lasting relief, then a thorough evaluation of every nasal sub-structure is important for a definitive diagnosis and surgical management. Three areas of each nostril are usually addressed surgically to alleviate nasal obstruction: the medial wall formed by the septum, the lateral wall lined by the turbinates and the nasal valves, along with alar nasi.

This chapter addresses the nasal obstruction secondary to the deviated nasal septum. It covers the conventional management of cartilaginous septal deviation and introduces a newly developed technique, using the laser. Laser cartilage reshaping (LCR) is a minimally invasive technique used to reshape deviated portion of the septal cartilage. A specific laser is used for its *non-ablative* thermal effect on the cartilage to alter its tensile strength to achieve a new, unobstructed configuration.

2. Deviated nasal septum

Nasal septum consists of cartilaginous and bony partition, covered on either side with muco-perichondrium and muco-periosteum respectively, containing blood supply to the cartilage and the bone. The septum is rarely in the exact midline; mild to moderate asymptomatic deviations are not uncommon and do not require correction. Septal deviation may be due to trauma, but in most cases, no definitive history is available. Only when they are symptomatic, management options are considered.

The onset of symptoms may be precipitated by contributory factors such as enlarged turbinates, allergic rhinitis, etc. In the first place, contributory factors must be treated to alleviate symptoms. If the symptoms persist, then correction of the deviation may be considered.

3. Symptoms

Although the leading symptom is difficulty in breathing, patient may come with epistaxis due to drying of mucosa leading to crusting, recurring sinus infections, headaches and, obstructive sleep apnoea (Fettman *et al*., 2009). The symptoms of allergy may be present, with engorgement of turbinates, making the symptoms of obstruction worse. In such cases, anti-allergic treatment must be exhausted before embarking upon surgery for septal deviation. Reduction of turbinates may be necessary at the same time as surgery for septal deviation. Laser cartilage reshaping described in this chapter excludes all

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such cases, as well as those due to a number of other factors contributing to the symptom of nasal obstruction, such as polypi.

In the past, submucous resection was the method of choice and involved nasal packing and in-patient stay. Refinements in techniques resulted in the introduction of septoplasty. This is carried out as open surgical procedure, or via endoscope (Sautter and Smith, 2009).

4. Submucous resection

The conventional septal correction dates back to 1902 (Freer, 1902) and 1904 (Killian, 1904) when Freer and Killian described the *submucous* resection (SMR) of the deviated cartilage and the bony septum, including the vomer and perpendicular plate of the ethmoid. Submucous resection is thus an extensive resection of cartilage and bone and is not without significant cosmetic and other risk described in the next section.

4.1. Risks and benefits of conventional dissection of septum

While a wide access allows a thorough surgical procedure for removal of all obstructing cartilage and bone right up to the posterior end of the septum, an overzealous removal of the dorsal and caudal support results in an unsightly tip drop with a saddle-shaped profile, an invitation to litigation.

Elevation of mucoperichondrium on the convex side is difficult since it is very thin due to stretching by the deviated cartilage and the spur. Not infrequently, it suffers from tears. Gross dissection may result in much loss of tissue and the healing leaves behind a perforation in the septum. If small, it may produce an embarrassing whistling sound with breathing.

Other risks exist in the form of postoperative bleeding, haematoma and infection. Septal haematoma following SMR is a serious risk, since it remains unattended as the patient has been discharged home. It lifts the mucoperichondrium and cuts off the blood supply of the cartilage resulting in avascular necrosis and infection. Gross avascular destruction of cartilage leads to saddle-shaped deformity.

5. Septoplasty

In 1947, Cottle introduced the hemitransfixion incision and the practice of conservative septal resections to preserve most of the structural integrity of the septum evolved. Septoplasty entails reshaping and repositioning of the cartilage. Any removal is kept to a minimum. After elevating the mucoperichondrial flap, full thickness cuts are made in the deviated cartilage in a checkerboard design or as several horizontal lines. This technique weakens the tensile strength of the cartilage. Small wedges of cartilage are removed from the convex side to accommodate the scored and straightened cartilage in the midline position.

6. External nasal approach

In external nasal approach, the skin and the soft tissue is elevated from the nasal tip cartilage. A sharp midline dissection identifies the anterior septal edge. The mucosal flaps are raised bilaterally. The external nasal approach provides the most direct view of the anterior and dorsal septum, all the way to the posterior edge of the septum. However, extensive dissection along the dorsum and avulsion of the cartilage may damage the ethmoid and the cribriform plate. A CSF leak is the result.

7. Morselisation

Morselisation involves crushing the cartilage with forceps until its springy property is destroyed. Morselisation is rarely practiced since it is largely an uncontrolled destruction of the elasticity of the cartilage.

8. Surgical outcome following conventional septoplasty

Septoplasty is not always successful and subjective outcomes are not promising. Dinis and Haider (2002) found that only 42% of septoplasty patients thought they had good-to-excellent results. Moderately successful results were found in 35% and poor to mediocre results in 23%.

Complications include epistaxis, infections, pain and septal perforation (Bloom *et al.*, 2009). Finally, aesthetic sequelae are well known and include loss

Table 1. The NOSE Score (Stewart *et al.*, 2004)

Symptoms over the past month	Not a problem	Very mild problem	Moderate problem	Fairly bad problem	Severe problem
Nasal congestion or stuffiness	0	1	2	3	4
Nasal blockage or obstruction	0	1	2	3	4
Trouble breathing through my nose	0	1	2	3	4
Trouble sleeping	0	1	2	3	4
Unable to get enough air through my nose during exercise or exertion	0	1	2	3	4

of tip projection, supra-tip depression and columella retraction (Daudia *et al.*, 2006).

9. Laser technology to correct deviated septum

Introduction of lasers in clinical practice prompted Kamami to use the CO_2 laser to vaporise the offending cartilage (Kamami, 1997). The procedure was termed laser-assisted septoplasty.

10. Laser-assisted septoplasty

A two- to three-mm vertical strip of the septal cartilage *along with* the overlying mucoperichondrium was vaporised. The procedure was undertaken in highly selected cases where the septal convexity was prominent on one side, whereas the contralateral side was in the midline. The vaporisation was carried out under local anaesthesia. The healing was reported to be uneventful and crusting was minimal.

The procedure did not gain momentum (Chapter 53), most likely due to very limited number of septal deviations suitable for laser vaporisation.

11. Laser cartilage reshaping (LCR)

Laser cartilage reshaping was first proposed by Emil Sobol in 1992. Chapter 61 covers the basic science in detail, and it will not be repeated here. The procedure is limited to strict indications (Daudia *et al.*, 2006; Bourolias *et al.*, 2008), as presented in this chapter.

12. Laser-induced mechanism when used for reshaping

The desired effect in laser-induced reshaping is proliferation and regeneration of cartilage cells. Long-term proliferation and regeneration process may determine the long-term stability of the final shape. However, given the stability of cartilage obtained after only *one week* of splintering (Leclère *et al.*, 2010), the following contributory factors may be involved:

- A direct effect on the radial curvature of septal cartilage;
- A mechanical action from the speculum itself.

Biopsies would be required to determine the exact mechanism of action, but these are difficult to justify from ethical standpoint.

13. Selection of patients

Both dosimetry and selection criteria for LCR-DNS are most important considerations and should be strictly adhered to.

13.1. Medical history

In addition to the usual factors, medical history should elicit if the obstruction is unilateral or bilateral, permanent or recurrent, it’s obvious precipitating factors such as seasonal appearance, hormonal dependency, or occupational basis. Any history of trauma is confirmed. Previous nasal surgery is a contra-indication to LCR-DNS.

The use of prescription medications should also be actively highlighted since it can cause extensive osteocartilaginous destruction within the septum. From a medico-legal point of view, sense of smell should be systematically assessed and recorded in the case notes. Objective assessment of the symptoms should be performed both before and after the procedure, according to the NOSE score (Stewart *et al.*, 2004, i, ii) (Table 1).

13.2. Endoscopic assessment

Endoscopic assessment gives a much better view of the airway without distorting the anatomy as is the case with the Thudicum speculum which forces the entrance of the nose to open, and, in the process, misses the alar collapse. Both internal and external nasal valve areas should be assessed for obstruction. An anterior rhinoscopy and naso-endoscopy should be systematically performed before LCR-DNS in order to exclude patients with inferior turbinate hypertrophy, adenoid hypertrophy, tip stenosis, or nasal polypi. Cartilage deformities should be differentiated from bony deformities.

To quantify the symptoms and measure their post-operative improvement, anterior rhinomanometry should be performed before and after the procedure.

13.3. Contra-indications

Contra-indications are directly linked to the nature of the pathology. If the obstruction is not caused by a cartilaginous deformity of the septum alone, and is wholly or in part due to a bony septal deformation, or collapse of the alar wall causing narrow valve, then, conventional surgery will be more appropriate. Previous septal surgery and previous trauma are also a contraindication for this technique since it can lead to additional cartilaginous damage due to laser thermal energy. Patients who use recreational drugs (*e.g.* cocaine) generally are not suitable candidates to laser reshaping, given the possible increased vascularity of mucosa, crusting or even exposure of the cartilage due to the effects of their drugs. Previous laser reshaping is not a contraindication and the technique can be repeated if first attempt at LCR-DNS does not meet patient's expectation.

14. Patient consent

The patient should be informed about all the possible risks inherent to the procedure. Early complications include burns and dermatitis that can be avoided by using correct laser parameters, standardising the procedure and strict adherence to inclusion and exclusion criteria. Inherent to the technique, there are no suture complications and no bleeding. Patient should be informed of the possible delayed risks of altered sensitivity, infection and keloids, and possible failure to achieve relief. The authors encountered none of these symptoms in their patient cohort of three series.

15. Choice of laser wavelength

Since the first use of CO_2 laser for septorhinoplasty by Selkin (1985), many wavelengths have been tried on inferior turbinate or cartilaginous septum including potassium-titanyl phosphate (KTP) laser (λ = 532 nm, power: 15 W, continuous mode) (Levine, 1991), CO_2 laser (λ = 10.6 µm, power: 10 W, pulsed mode) (Kamami *et al.*, 2000), or holmium:YAG laser (λ = 2.1 µm, pulse duration: 500 microseconds, pulsed mode: 0.2–0.4 J, pulse repetition rate: 5 Hz) (Ovchinnikov *et al.*, 2002).

Whereas success rates were impressive, disadvantages of the technique included epistaxis, synechae between the septum and the turbinates and excessive coagulation of the surrounding mucosa. CO_2 laser and holmium: YAG laser are efficiently absorbed by the water contents of the mucosa; their effect is thus maximum on the surface, and continual strikes leads to conduction of energy in to deeper tissues which overheat. KTP-532 is highly absorbed by haemoglobin and thus has a selective tissue effect. To overcome these effects, Bourolias *et al.* (2008) recommended the use of wavelengths around 1.5 µm. At this wavelength, the heating of the cartilage is homogenous

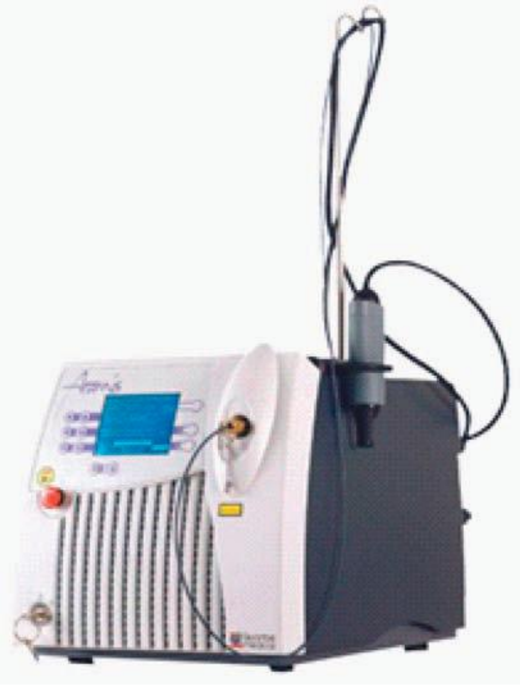

Fig. 1. 1.54 µm Er:Glass laser (Aramis, Quantel Derma GmbH, Erlangen, Germany)

through its entire depth, without any damage to the surrounding tissue.

Since 2004, we have developed a non-invasive technique using a specific 1.54 μm Er:Glass laser (Aramis, Quantel Derma GmbH, Erlangen, Germany) to reshape cartilage (Mordon *et al*., 2004; Trelles *et al*., 2006; Leclère *et al*., 2010; 2011) (Fig. 1).

The handpiece, with a sapphire window placed in contact with the tissue, was developed for three reasons:

- It protected the superficial layer of the tissue, avoiding coagulation of the mucosa of the septum;
- It provided maximum comfort for the patient from cooling before, during, and after the treatment;
- It was possible to use higher energy to treat cartilage of varying thicknesses.

16. Anaesthesia

Contact cooling makes the treatment tolerable, but topical anaesthesia is usually required. Sponges soaked in Articaine solution and adrenaline 1:100,000 are easily applied on each side of the nose for five to ten minutes prior to the procedure.

17. Instrumentation and laser procedure

The instrumentation includes a nasal speculum and the 1.54 μm Er: Glass laser. The laser is connected to a handpiece, allowing a 4-mm spot size laser beam delivery at 90° and concurrent contact-cooling of the sapphire window placed in contact with the mucosa. The cartilaginous part of the septum is carefully straightened and fixed in the median position using a nasal speculum. The treatment consists of a series of 50 spots applied homogenously on the mucosa in contact mode on both sides of the septum (Fig. 1). Each spot included five stacked pulses (3.3 milliseconds, 500 W, 2 Hz, 50 J/cm^2 cumulative fluence), applied using a 4-mm chilled handpiece at +5°C temperature.

18. Postoperative management

Nasal packing (Invotec, USA) is placed after the procedure for 7 days. A non-steroidal anti-inflammatory drug (NSAID) is always prescribed to the patients for three days and a routine antibiotic prophylaxis, for five days.

19. Follow up

Follow up is simple, limited to ensure that there are no complications such as burns of the target and non-target tissues. The nasal packing is carefully removed.

20. Risks and benefits of the technique

Compared to conventional septoplasty, LCR-DNS is a non-surgical procedure thus the usual post-operative risks associated with the conventional septal surgery are inherently non-existent.

This procedure offers several potential advantages:

- It is carried out as an office-based procedure;
- Imbibition anaesthesia is effective and well tolerated;
- The treatment is quick and without scars;
- The follow-up is simple.

Finally, if the anticipated outcome is compromised, further LCR-DNS is entirely possible since, being non-ionising emission, there are no cumulative effects of the treatment.

21. Treatment outcome

Patient discomfort and subjective outcomes are best evaluated using the NOSE score assessed before and after the procedure (Table 1). Rhinomanometry demonstrates an increase in air flow and improvement to air in-flow resistance, confirming the subjective improvement.

22. Cost considerations

LCR-DNS is cost effective when the following issues are factored in:

- It eliminates the need for full scale local or general anaesthesia;
- The treatment can be performed in an office setting;
- The treatment does not call for high skill level and is easily delegated to assistants;
- The cost-effectiveness is not achieved at the expense of sub-optimum or short-term result.

One limitation of this procedure is that it can only be used in a highly selective patient cohort. A long term trial will determine what percentage of the *overall* patients with nasal obstruction can be treated with LCR-DNS, and will reflect its true potential. At this initial stage, however, the sheer simplicity and the minor nature of the procedure itself is an attractive proposal worthy of a serious pursuance of this elegant technique.

23. Discussion

Laser septo-chondro-correction was first introduced by Ovchinnikov in 2002. Instead of using wavelengths which are maximally absorbed superficially, Bourolias *et al*. (2008) advocated the use of wavelengths around 1.5 µm, permitting homogenous heating of cartilage in its entire depth. Since the procedure does not involve a surgical cut, there is no bleeding.

In their series of 64 patients, they concluded that it is a modern, promising, safe, bloodless and minimally invasive procedure that takes no more than 20-25 minutes. NOSE score improved from 17 to 10. Rhinomanometry assessment showed increase in air flow and improvement in air in-flow resistance. In our first series on 12 patients (Leclère *et al*., 2010), mean NOSE scores improved considerably (11.6 to 5.3). Rhinomanometry assessment showed an increase in air flow (+19%) and improvement to air in-flow resistance (-16%), consistent with subjective improvement. Furthermore, our outcomes with this non-invasive technique are not only comparable to conventional septoplasty, but there are some distinct advantages as follows:

- The procedure is simple and quick. The whole procedure can be performed in less than 20 minutes;
- If the anticipated improvement is not forthcoming then the procedure can be repeated;
- Symptomatic improvement is demonstrated by NOSE score and rhinomanometry;
- The conventional surgical correction is not excluded;
- The procedure is cost effective without compromising the equitable outcome with conventional surgical correction.

24. Conclusion

Apart from the application of laser reshaping of the septal cartilage, there are a number of other potential applications where this new technology can be applied. Thus the technique is multi-disciplinary and the initial capital outlay can easily be justified.

The LCR for protruding ears is described in Chapter 63. This technique was developed at the INSERM institute (French National Institute of Health and Medical Research) in Lille (France), with a view to both improving patient comfort and reducing complications (Mordon *et al*., 2004; Trelles *et al*., 2006; Leclère *et al*., 2010; 2011).

Based on our previous observations, the 1540 nm Er:Glass laser appears to be an ideal wavelength for cartilage reshaping:

- The wavelength's penetration depth matches the thickness of the cartilage, allowing for the regeneration and proliferation of cartilaginous cells;
- There is no discomfort to the patient due to contact cooling;
- The extent of correction appears similar to that obtained by conventional techniques;
- LCR-DNS provides a smoother and more natural correction than conventional techniques with no scarring.

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MCQ – 62. Clinical application of laser cartilage reshaping for deviated nasal septum

1. Laser cartilage reshaping (LCR) is possible for
   a. Bony spurs
   b. Cartilaginous spurs
   c. Deviated nasal cartilage
   d. Posterior spur
   e. Dislocated cartilage

2. LCR is contraindicated
   a. When there is history of previous trauma involving the nasal septal cartilage
   b. If the patient is taking recreational drugs
   c. If the main obstruction is bony rather than cartilaginous
   d. If there are several other complementary factors to nasal obstruction, which have not been treated successfully
   e. All of the above

3. The main advantage/s of the LCR is
   a. It is office based and therefore cost effective
   b. It does not involve a surgical cut
   c. It is well tolerated by the patients
   d. It can be repeated if necessary
   e. It can be undertaken with almost any laser available in the ENT department

4. The possible risk to the patient
   a. Saddle shaped deformity
   b. Procedure may have to be repeated if the result is suboptimal, without any other associated obstructive pathology such as nasal polyp
   c. Continuing nasal obstruction
   d. Perforation of the septum
   e. Burns and dermatitis

5. The key factor to success is
   a. High level of expertise
   b. Correct equipment and instrumentation
   c. A careful selection of patients
   d. Meticulous attention to details in respect of dosimetry
   e. Cooperation of the patient

Chapter 63

Clinical application of laser cartilage reshaping for protruding ears

F.M. Leclère, M. Trelles, I. Petropoulos and S.R. Mordon

1. Introduction

Although pinna in humans plays a very little part in the function of hearing, its deviation from 'normal' anatomical configuration is immediately noticeable. A child with protruding ears, or 'bat ears', may be a subject of much teasing from his or her schoolmates. In the girls, the bat ears become even more prominent if they tie their hair above the head, say for ballet practice.

While 'personal' opinion about his or her ears as to the deviation from 'normal' are important, a protrusion of more than 15-20 mm from the tympanomastoid plane makes the pinna stand away noticeably, from the normality. A 30-degree angle between the planes is certainly not normal and does not need a confirmatory measurement.

The prominence is due to two factors, lack of formation of antihelix fold, or, unusually deep welled concha, or both. The ear lobe also may be rather large and protruding but on its own without the presence of protruding helix, it is not noticeable. Apart from deviation from normality, congenital deformity of pinna also exists in a variety of forms but their management is not relevant in the context of this work, and will not be covered.

2. The relevant anatomy of the pinna

The biomechanical properties of the cartilage of the pinna are not constant and, in fact, there are significant individual differences. An anathema that one size fits all is never more false than in the case of the cartilage of pinna.

The fold of the antihelix divides the concha anteriorly and the scapha posteriorly. If the fold is ill-formed, concha and the scapha form a continuous concavity which ends at the helix. The concha, scapha and the helix thus form almost a right angle from the temporal plane, thus resulting in protrusion of the pinna. The extent of the protrusion of the scapha-helix away from the plane of the temporal plane is determined by the acuteness of the fold of the antihelix. A broad or non-existent antihelix results in imperceptible merging of the concha and the scapha, limited posteriorly by the helix. It is obvious that the formation of a smoothly curved antihelix holds the key to a successful outcome of any surgical or non-surgical procedure (Fig. 1).

3. Symptoms

Protruding ears *per se* do not cause any 'symptoms' in the usual sense. Children younger than five years of age are rarely aware of their protruding ears. However, the parents may bring the child to have surgical correction to spare him or her embarrassing schooling experience of being picked at. Any decision to operate on a child of young age should be taken with care, since postoperative care may not be optimum due to child's inability to comply.

If the patient is adult, then a full discussion is necessary to assess the 'reason' and correlate it to the possible surgical outcome. The procedure assumes

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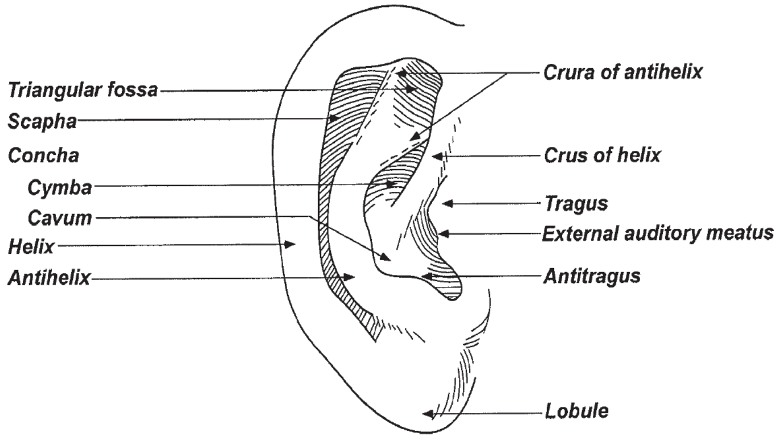

Fig. 1. The anatomy of the pinna.

aesthetic basis rather than merely being 'picked at' in the school days.

4. Conventional surgical procedures

The high incidence (13.5%) of protruding ears, with its associated psychological distress for either sex and at any age has drawn attention of medical fraternity to its surgical correction long ago. Dieffenbach in 1845, was the first physician to report the treatment using a retroauricular skin excision. Since then, numerous techniques have been described and the techniques that have stood the test of time are the simplest, most reliable, least likely to cause complications and the ones that offer the most natural post-operative correction (Thorne, 2007). These will not be covered here. Suffice it to say that some experience in plastic surgical techniques is useful to get an optimum result. It is also necessary to appreciate that all open surgical procedures carry some risks, although their incidence is small. The reported risks include haematoma, infection, hypertrophic scars and keloids. Recurrence of protrusion, although not common, can occur where thick conchal cartilage overcomes the strength of the anchoring sutures. Repeat procedure needs a careful assessment and corrective steps.

Seemingly successful otoplasty may be negated due to biomechanical forces not sufficiently corrected, or, from external factors due to movement of dressing or pressure on the operation site when asleep. Cutting the cartilage of antihelix may result in irregularity which lacks the natural contour of the normal pinna.

Overcorrection may hide the helix. While such appearance is not uncommon in normal ears, it is particularly noticeable in otoplasty patients.

Monofilament sutures used to correct the deformity may erode through the posterior skin which is rather thin.

4.1. Laser cartilage reshaping

Chapter 61 covers the basic science of cartilage reshaping with the laser energy in detail, and will not be repeated here. This chapter goes to the next step of application of the pure science to clinical cases, with selection, methodology and risk and benefit issues.

Since the preliminary work of Sobol *et al.* (1993), cartilage reshaping has gained an interest, particularly in the field of nasal and plastic surgery. Historically, laser assisted cartilage reshaping was first developed for septoplasty (Bourolias *et al.*, 2008). In 2004, Mordon *et al.* proposed the possibility to adopt this technique for protruding ears. The animal model chosen was the rabbit as it was easily accessible to the laboratory and has large ears. However, as compared to the human ear, the rabbit ear has powerful auricular muscles, thus limiting its suitability.

5. Experimental set-up for LACR on animal model

In the laboratory, LACR treatment (Laser Assisted Cartilage Reshaping) was performed *in vivo* using a 1540 nm Er:Glass laser connected to a handpiece with an integrated cooling system (Fig. 2). The treatment consisted of 15 contiguous spots (3 milliseconds, 7 pulses, 12 J/cm², 2 Hz, cumulative fluence 84 J/cm ²) applied in eight parallel rows along the ear. An aluminum preformed splint was then placed for a period of one week. Biopsies, performed during follow-up, showed the absence of burns (one week after surgery) and a proliferation of chondroblasts (three weeks postoperatively). At six weeks, there was thickening of the cartilage layer. This newly formed layer acts as a *biological brace* that holds the ear in its desired shape. In the five years that followed, this technique was successfully introduced on humans and currently about 80 patients (Trelles *et al*., 2006; Leclère *et al*., 2010; 2011) have benefited from this technique, as detailed in this chapter.

6. Selection of patients

Within the first three months of life, protruding ears are best treated non-surgically by moulding, as the cartilage is still malleable from the influence of maternal oestrogens. Any history of previous surgical correction is important since LACR is contraindicated in such cases.

7. Age selection for LACR

Although previously conventional otoplasty was advised for children at the age of four onwards and, preferably before the Kindergarten, the current trend is six years as the earliest age when otoplasty should be discussed with parents and the child and conventional correction performed (Spielmann *et al*., 2009). In contrast, LACR can be performed on patients of all ages (Leclère *et al*., 2011) (Figs. 1 and 2), since there is very little post-procedure care needing patient compliance and cooperation.

8. Clinical examination

The surgeon should assess and record the three major pathological characteristics of the protruding ear deformity:

- Poorly defined or absent antihelical fold;
- Conchoscaphal angle > 90°;
- Exaggerated concha.

The skin should be carefully examined in order to exclude discharging ears, otitis externa or scars. To assess the post-operative improvement, cephaloauricular distances should be carefully measured before and after LACR (Leclère *et al*., 2011). Skin sensation should be also carefully evaluated before and after the procedure.

9. Patient consent

The patient should be informed of all possible risks and benefits (see paragraph 18 of this chapter) arising from the procedure.

10. Contraindications for LACR

Previous auricular surgery and congenital malformation other than protruding ears are a contraindication for this technique. The technique can be repeated if the result does not meet expectations (Leclère *et al*., 2010). A severe conchal deformity is a relative contraindication because the LACR technique will not correct it completely (Trelles *et al*., 2006; Leclère *et al*., 2010; 2011).

11. Laser-induced mechanism

Both animal and clinical biopsies performed after LACR have shown the growth of hyaline cartilage at the periphery of the irradiated zone where the transformation of cartilage matrix occurs. Mordon *et al*. (2004) and Trelles *et al*. (2006) concluded that the cartilage regeneration process may influence the long-term stability of the final shape. For detailed coverage, see Chapter 61.

12. Choice of laser wavelength

The 1540 nm Er:Glass laser is an ideal wavelength for cartilage reshaping for the following reasons:

- The wavelength's penetration depth matches the thickness of the ear cartilage;
- Contact cooling makes the treatment very tolerable;
- The degree of correction appears similar to that obtained by conventional techniques.

The fluence (energy delivered to the irradiated cartilage surface) was determined by calculation and validated in experimental animals. The concern here was to obtain the temperature rise required for tissue remodeling without altering both skin and cartilage. During the transition to the clinic, we used the fluence of 84 J/cm². Our experimental finding showed that a lower fluence (70 J/cm²) did not lead to sufficient heating. Beyond 84 J/cm², there is no efficiency gain, but a potential risk of injury to the skin.

13. Anaesthesia

Contact cooling makes the treatment very tolerable, eliminating the need for anaesthesia.

14. Instrumentation and laser procedure

The 1540 nm Er:Glass laser (Aramis, Quantel Derma GmbH, Erlangen, Germany) is set at 12 J/cm^2 per pulse (Trelles *et al*., 2006; Leclère *et al*., 2010; 2011). The treatment requires at least 50 (x7) pulses on each side to be effective (seven stacked pulses, 2 Hz, 84 J/cm^2 cumulative fluence), applied using a 4-mm spot handpiece with integrated cooling (Koolburst, Quantel Derma GmbH, Erlangen, Germany) on both sides of the entire helix and concha (Fig. 2).

15. Postoperative management

Immediately after irradiation, a silicone elastomer (Hydro-C, Detax, Ettlingen, Germany) is inserted inside the helix to give it the desired shape. Three minutes later the elastomer hardens and a solid mould is obtained. Patients are asked to wear this mould at all times for the first two weeks and then only at night for an additional four weeks (Fig. 3). A non-steroidal anti-inflammatory drug (NSAID) is prescribed to all patients for three days.

16. Outcomes and advantages of the technique

LACR provides a more natural curvature than conventional techniques (Figs. 1 and 2). In our latest series, mean patient satisfaction was impressive, with a reported score of 8.6/10. This excellent rate of patient satisfaction was confirmed objectively by measuring the cephalo-auricular distance.

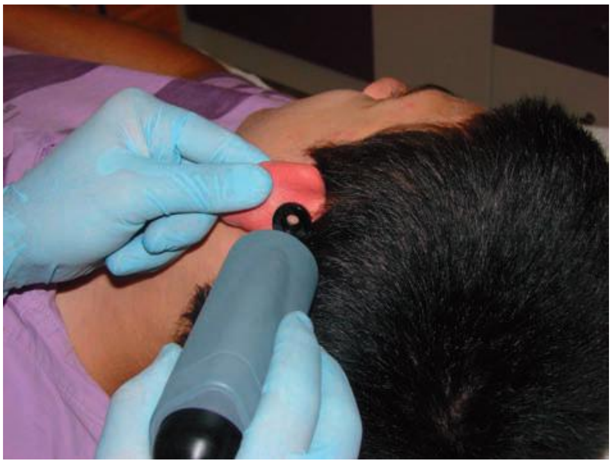

Fig. 2. Laser pinnaplasty.

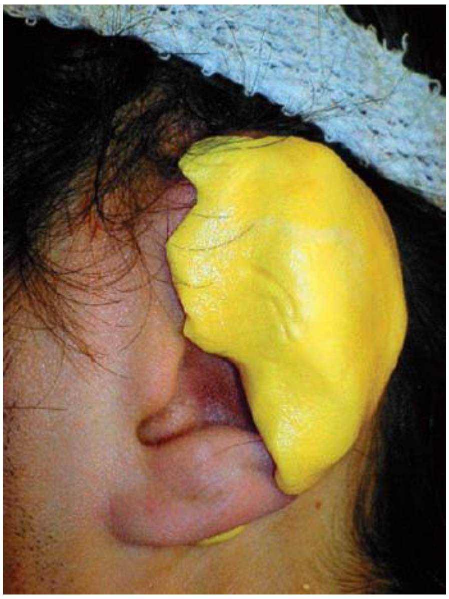

Fig 3. Postoperative mould.

17. Patient acceptance

This procedure is well tolerated because of the following (Trelles *et al*., 2006; Leclère *et al*., 2010; 2011):

- This is an outpatient procedure, not requiring an anaesthetic;
- The treatment is quick and without scars;
- The follow up is simple;
- If patient expectations are not met, a second LACR procedure is possible.

18. Risk and benefit issue

- LACR provides smoother and more natural curvatures than conventional techniques, without scarring (Leclère *et al*., 2010). There are no suture complications and no bleeding, inherent to the technique.
- In the early postoperative period, burns and dermatitis is possible, however, such risk is avoided by using appropriate laser parameters and mould (Trelles *et al*., 2006; Leclère *et al*., 2010; 2011).
- During late follow up, asymmetry, recurrence, hypertrophic and keloid scars, though absent in our series, should be considered.
- Changes in skin sensitivity and growth are reported in as many as 7.5% of the patients with conventional surgery (Caouette-Laberge *et al*., 2000). However, these outcomes have not been encountered in our LACR series.
- LACR, is a non-invasive procedure performed without anaesthesia. There is minimum postoperative risk when compared with conventional surgery. Any risk is almost completely eliminated by careful selection of laser parameters and patient compliance in the use of mould as described. The follow up is simple. Accurate shaping of the mould and its compliant use seem to be the key factors which largely influence the outcome of LACR.

19. Cost considerations

As in the case of laser septal reshaping, the reshaping of protruding ear is not expensive for the following reasons:

- It eliminates the need for anaesthesia;
- The treatment is performed in an office setting;
- The treatment is easy to perform and can be delegated to assistants;
- The reduced costs do not result in sub-optimal results. In fact, the smooth curvature of the antihelix following LACR is aesthetically much more pleasing.

20. Discussion

Surgical correction of protruding ears by otoplasty is of great benefit to children in alleviating their psychological problems and improving social integration (Cooper-Hobson and Jaffe, 2009). Although conventional procedure is associated with very little morbidity, it does have some disadvantages inherent to the procedure. It requires general anaesthesia and inpatient stay. A scar is inevitable. Although risk factors are uncommon in experienced hands, nevertheless, they do exist.

Since 2004, we have developed a non-invasive technique using a 1540 nm Er:Glass laser for treating ear protrusions in human (Trelles *et al*., 2006; Leclère *et al*., 2010; 2011). Since our first report in 2004 on the animal model (Mordon *et al*., 2004), about 80 patients have been treated using this technique and three different studies have been published. The first series, performed on a small number of patients, allowed us to report an excellent ability to adapt migration of LACR technique from the animal model to the clinic (Trelles *et al*., 2006) with the following outcomes:

- The fluence used did not cause burns.
- In this preliminary study on 12 ears in eight patients, biopsies performed in each case showed a thickened cartilage after two weeks, all with an intact matrix. Viable chondrocytes were noted.
- Unlike results using CO_2 and YAG lasers, remodeling obtained with 1540 nm Er:Glass was stable and comparable, or better to that achieved with conventional surgical techniques.

In a second series of 48 ears in 24 patients, the postoperative follow up was without complications, except for six patients who suffered from mild dermatitis (Leclère *et al*., 2010). This second series allowed us the following:

- To emphasise the reduced short-term complications following procedures on a larger cohort.
- Demonstrate its safety in children since ten children were included in the study.
- Moreover, this series highlights the importance of the mould. A poorly designed mould increases the incidence of dermatitis and its early removal increases the risk of inadequate correction.
- Additionally, this series demonstrated that lower fluence (70 J/cm²) did not sufficiently heat the cartilage. Conversely, energy levels above 84 J/cm² did not increase efficacy, but did increase the potential for injury to the skin.
- Finally, in this larger series, a more natural appearance of the ears was noted after LACR compared to conventional techniques.

A third, recently published series on 32 ears emphasised the very low short-term and long-term complications (Leclère *et al*., 2008). It also demonstrated objectively, using measurement of cephalo-auricular distances, that this technique was extremely stable in time and that results could be deemed as permanent.

Other teams have tried to duplicate our work (Holden *et al*., 2009), but are still faced with the challenge of the correct use of the mould or the difficulty in obtaining approval for clinical trials.

Another approach was recently proposed by Ragab (Ragab, 2010). Use of the CO_2 laser permitted cartilage reshaping with both vaporisation and incisions. In his technique, the open approach allowed precise laser application and cartilage suturing provided great stabilisation. Post-operative care involved wearing a simple headband for a week, representing a considerable advantage. However, this method uses both laser and surgery, which undermines the basis of a technique whose primary objective is simplicity to perform, elimination of need for anaesthesia and minimum complication rate. Additionally even if their results seem attractive, larger series are required to assess risk factors arising from using sutures, *i.e.*, haematoma, hypertrophic scars and keloids.

Finally, among all LACR applications, this technique currently stands alone in providing cartilage biopsies, long-term clinical follow up and a standardised technique. Other applications currently studied for deviated septum (Bourolias *et al*., 2008; Leclère *et al*., 2010; Choi *et al*., 2008) – (described in Chapter 62), alar cartilage reshaping (Leclère *et al*., 2010) or costal graft reshaping (Baum *et al*., 2011; Sobol *et al*., 2011) should provide more histological and clinical evidence in order to clarify their action mechanism.

21. Conclusion

LACR appears to be a safe, effective and reproducible method for the treatment of protruding ears. Other current application of this technique, laser assisted septal cartilage reshaping (LASCR) for septum deviation, is described in Chapter 62.

Acknowledgement

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MCQ – 63. Clinical application of laser cartilage reshaping for protruding ears

1. In protruding ears the prominence is due to
    a. Deformed concha
    b. Deformed scapha
    c. Lack of formation of antihelix fold
    d. Unusually deep welled concha
    e. The concha, scapha and the helix which together forming almost a right angle from the temporal plane

2. The key to a successful outcome of any surgical or non-surgical procedure is
    a. Restoration of correct angle between scapha-helix and the temporal plane
    b. The formation of a smoothly curved antihelix
    c. Reducing of the angle between pinna and the temporal plane by stitching back the scapha
    d. Removing retro-auricular skin
    e. Scouring the flat cartilage and forming scapha and concha by applying anchoring sutures

3. Open surgical procedure carries a risk of
    a. Haematoma
    b. Infection
    c. Hypertrophic scars and keloids
    d. Recurrence of protrusion
    e. Irregularity which lacks the natural contour of the normal pinna
    f. All of the above

4. An ideal laser for LACR of protruding ears should
    a. Have a minimum collateral damage zone
    b. Should not require any contact cooling
    c. Should have penetration depth that matches the thickness of the ear cartilage
    d. Be appropriate for use under local or general anaesthesia
    e. Not cause eczema

5. Considering the above, an appropriate laser for laser-assisted cartilage reshaping (LACR) of pinna is
    a. Er:YAG laser
    b. Er:Glass laser
    c. CO2 laser
    d. KTP laser
    e. Ho:YAG laser

6. An ideal age for laser assisted correction of protruding ears is
    a. At the age of four
    b. A baby within a few months of birth
    c. At the age of six
    d. In adulthood
    e. At any age

7. The protruding ear should have a minimum of the following criteria for LACR procedure
    a. Poorly defined or absent antihelical fold
    b. Conchoscaphal angle > 90°
    c. Conchoscaphal angle > 70°
    d. Concha and scapha forming a deep cavity
    e. Exaggerated concha

8. The following are the advantages of LACR for protruding ears
    a. An outpatient procedure
    b. Does not require an anaesthetic
    c. Can be undertaken under local infiltration anaesthesia, if required
    d. The treatment is quick and without scars
    e. If patient expectations are not met, a second LACR procedure is possible

Section XI: Future Developments in Laser Applications

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Chapter 64

Clearing biofilms via laser shockwave

J. Krespi and V. Kizhner

1. Introduction

The recognition of the importance of the biofilms in relation to pathogenesis of infections associate with the long dwelling medical devices has risen steeply in recent years. Biofilms are clusters of bacteria that reside in a self-retaining surface adhering extracellular polymeric slime (EPS) matrix. Biofilms show a phenotypic resistance to antibiotics which are active against the same bacteria when in planktonic form (Desrosiers *et al.*, 2007). Multiple mechanisms are responsible for antimicrobial agents and immune system resistance. The EPS matrix is a complex material consisting of polysaccharides, proteins and nucleic acids of bacterial origin. Open channels run between the micro-colonies, allowing the delivery of nutrients and possibly communication by 'pheromone-like' signals. Cell to cell interaction induces the bacterial population to co-ordinate behaviour by changing patterns of gene expression, a phenomenon termed 'quorum sensing'.

2. Protection mechanisms

Various protection mechanisms by biofilm bacteria include programmed cell death of damaged cells, expression of stress-genes, production of antibiotic inactivating enzymes and antibiotic efflux pumps (Bhattacharyya, 2006). The three dimensional formation of biofilm with layered bacterial cells creates an active outer layer of bacteria which has a better nutrient access compared to the bacteria within deeper layers. This formation creates a quiescent and dormant inner layer which can replenish the outer shedding bacteria. The inner microenvironment is conditioned with low metabolic activity thus shielding the inner bacteria from antibiotic activity. In addition to eluding antibiotic therapy and the immune system, biofilms often induce a local chronic inflammatory host response which can result in tissue damage on which the biofilm bacteria can feed (Krespi *et al.*, 2008).

Biofilms colonisation of indwelling or implanted devices is particularly problematic in medicine. As permanent and temporary indwelling medical devices are increasingly utilised, the number of infections with biofilms causing local or systemic chronic infections also rises. The implications of biofilm-related device infections range from low morbidity to severe systemic infections ending with mortality. These infections are directly correlated to length of time of device implantation. Otolaryngological indwelling devices include tympanostomy tubes, middle ear prosthesis, nasal/laryngeal stents, tracheal tubes cannulas and metallic hardware (Krespi *et al.*, 2011).

3. Aims and objectives

The eradication of biofilms from medical devices is a major healthcare concern. Our goal was to explore one possible solution to this problem. Rather than the aiming for the difficult goal of total biofilm eradication, our intent was to identify and disrupt

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the bacterial protective mechanism of biofilm and render it treatable by the body's immune system and/or antibiotics. In a preliminary study it was demonstrated that a Q-shock laser could be used to disrupt Pseudomonas aeruginosa biofilms from polyethylene terephthalate (PET) sutures (Krespi *et al.* 2011). In the present study the potential for laser disruption of biofilm removal from various devices with an emphasis on orthopaedic and cardiovascular devices using stainless steel screws and nickel titanium alloy (NiTinol) stents as representative devices was assessed. In addition the removal of biofilm over time was quantified to determine the time scale of treatment.

4. Equipment and instrumentation

A small Q-switched Nd-YAG laser (ARC Laser, Nuremberg, Germany and Valam, New York, NY) was used to generate 'shock wave' (SW). The probe was coupled to a 300-micron optical fibre at one end and a probe with a small opening at the distal end. The proprietary hand probe was comprised of a titanium target at the tip absorbing the laser energy causing plasma effect later to be emitted by stress pulses. Titanium was chosen as a target material to generate plasma because of its excellent biocompatibility and high absorption coefficient with respect to the laser wavelength. Another important advantage of the solid titanium is its thermal conductivity compared with other metals.

The Q-switched Nd-YAG laser was set for a frequency of one pulse per second, each pulse lasting four to eight nano-seconds at a wavelength of 1,064 nm for this experiment while the output energy was between eight and 12 mJ. By exposing a small area to this intense power, an ionic state of matter, known as electrical plasma, was created. The biofilm was exposed to 10-20 laser generated pulses of shockwave. The pressure generated at the tip of the probe is estimated at 2 kbar. As plasma is retained within the probe tip, the shockwave leaves the probe without any temperature change.

5. Bacteria and medical devices

Biofilms of the Pseudomonas aeruginosa strain, PittD: YFP which has been constructed to constitutively expresses yellow fluorescent protein (YFP) and has gentamicin as a selective marker, were incubated in 1/10th strength in Luria-Bertani broth. Various medical devices, made from different materials, were then infested with biofilm. Plastic devices included fluoroplastic tympanostomy tube (Medtronic-ENT, Jacksonville, FL) and Shiley tracheostomy tubes (Mallinckrodt Pharmaceuticals, Hazelwood, MO). Metal devices included endovascular stainless-steel Wallstent (Boston Scientific/Scimed, Inc.) and coated and uncoated NiTi (nickel-titanium) stents (JNJ-Cordis Corporation, Brunswick, NJ), 316 L stainless steel orthopedic screws (Synthes, Paoli, PA). Polyethylene terephthalate (PET) implantable sutures (Medtronic-ENT, Jacksonville,FL) concluded the synthetic materials. The cultures were incubated at 37° C in a humidified 5% CO_2 atmosphere on a shaker table at 100 RPM. The medium was replaced daily, and the growth period was three days.

6. Imaging

After three days, the devices were rinsed with Ringer solution (Oxoid, Cambridge, UK) to remove loosely adhered bacteria and gently blotted dry on one side before being fixed to the bottom of a separate 35-mm Petri plate with epoxy glue. A small area of the surface, corresponding with the area immediately affected by the laser (approximately 1 x 1 mm) was imaged before, during, and after laser application using the time lapse function of a Leica TCS SP2 AOBS confocal upright DMRXE7 microscope (Leica Microsystems, Exton, PA) with either X10 air objective or a long working distance X63 0.90 NA water immersion lens.

7. Results

For a low power setting (eight mj) clearance of biofilm from a lined stent was seen after a median of 12 seconds, *i.e.*, 12 pulses (Fig. 1). When a higher setting of 12 mj was employed a median of nine seconds were needed. Lined stents receiving high power laser treatment were clear of biofilm after only 1.75 sec.

Fig. 2. shows disruption of biofilm between screw threads following laser exposure.

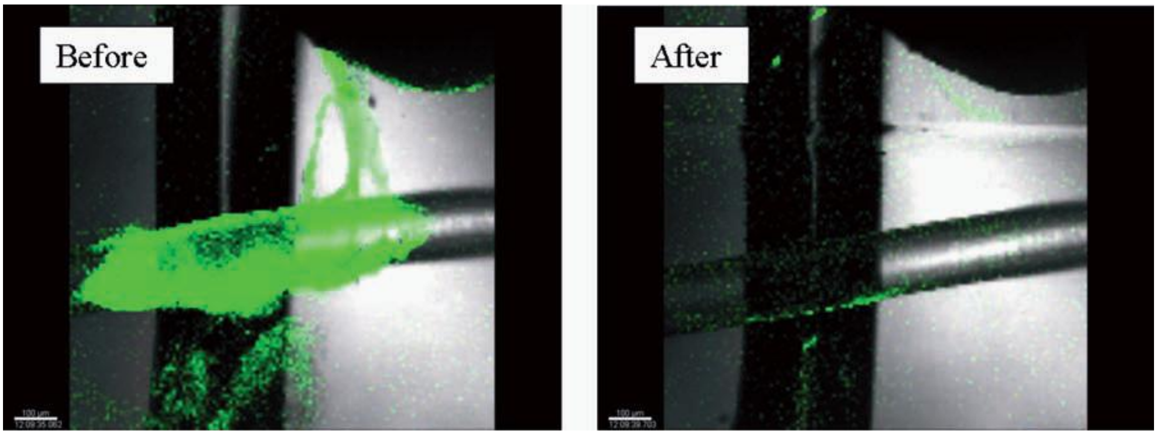
Before
After

Fig. 1. Clearance of biofilm from lined stent with power set at 12mj (superimposed fluorescence image on bright field microscopy).

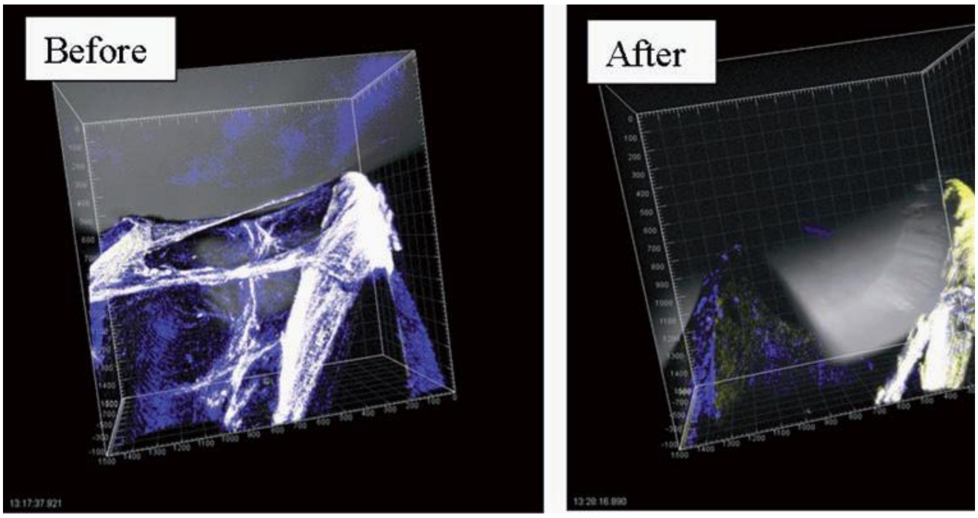
Before
After

Fig. 2. Clearance of biofilm from an orthopedic stainless screw (superimposed fluorescence image on bright field microscopy).

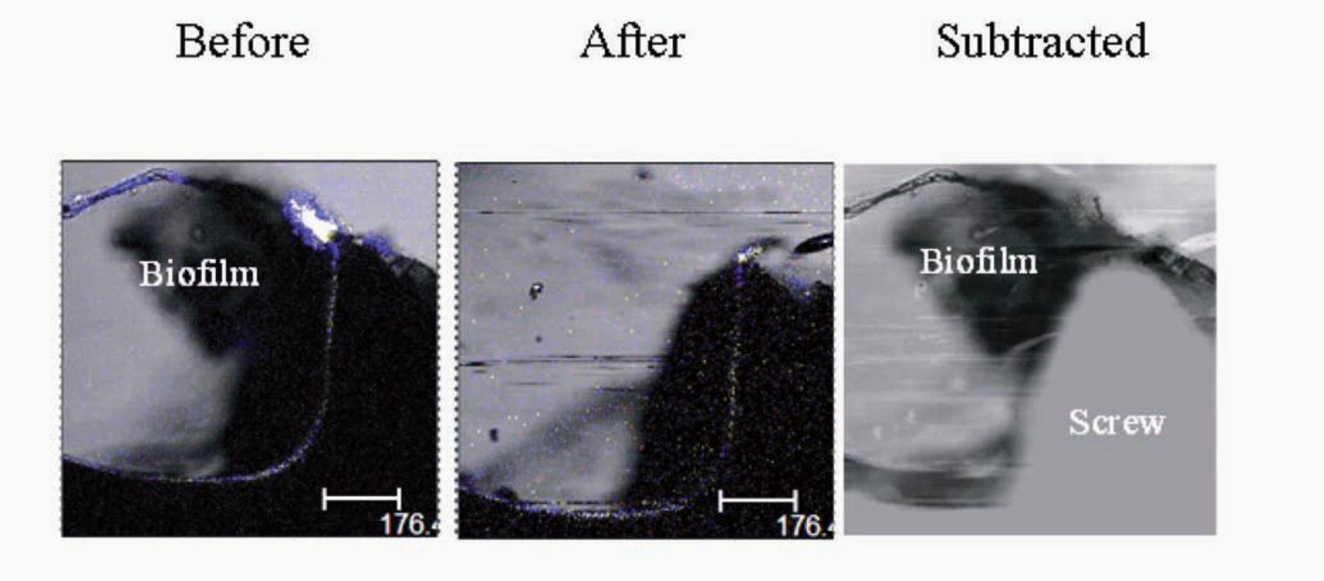
Before
After
Subtracted
Biofilm
176.
176.
Biofilm
Screw

Fig. 3. Orthopedic screw showing the subtracted clean screw area from the infested screw (superimposed fluorescence image on bright field microscopy).

8. Discussion

Attempts to eradicate biofilm induced infections have primarily resorted to antibiotics and disinfectants (such as Wang's study with gentian violet) with mixed results. Antibiotics delivered either systemically or locally with concentrations as high as 1000 fold of moxifloxacin were needed to eradicate Staphylococcal aureus biofilm, while other experiments failed to show Pseudomonas eradication with a concentrated solution of tobramycin. For staphylococcal infections rifampin combinations are the most evaluated. Topical treatments though are semi mechanical, depend on substance delivery, and have long-term material safety issues yet to be demonstrated.

The strategy for implantable medical device infections is somewhat different. Whenever possible, prevention is the first step, including the use of different coatings, such as antibiotic coatings with rifampin and minocylcine combinations, or antiseptic coatings with silver or chlorhexidine combinations. Catheter locks follow the same principle with antibiotic or antiseptic locks for prevention.

Bacterial eradication follows when prevention fails. With these current modalities in mind, our focus was on developing and testing a tool that could be easily applied in a clinical setting and would successfully dislodge biofilm in a repeatable manner that made it vulnerable to the body's immune system and/or antibiotics. Initially, biofilm was successfully disrupted in a cultured plate, leading to the testing of biofilm disruption on various medical devices. This study showed quantification of biofilm disruption on various and common medical devices in time. Employing a Q-switch laser technology allows one to control energy deliverance (shockwaves) with repeatable accuracy. Dislodgement of 97% of biofilm bacteria from different medical devices, made from different materials, such as vascular stents and orthopedic screws was undertaken. Specifically, removing 97.9 ± 0.4 % (mean ± 1SD, n = 3) of the biofilm from the surface of a Nitinol (NiTi) stent ranged from four to ten seconds.

This experiment represents the clinical efficacy and applicability in disrupting a majority of biofilms from a medical device. Compared to other methods, the shockwave method requires a very short, albeit focused method. While almost all of the biofilm is cleared, the dislodged bacteria were not assayed. As a result, one of the drawbacks of our experiment was the lack of surveillance upon the remaining biofilm and its ability to 're-group' and create another biofilm matrix; an issue which was not addressed in other experiments as well. As the biofilm is dependent on its structure for keeping antibiotics from penetrating the underlying bacteria in its core, breaking the 3D biofilm structure releases the bacteria in their planktonic shape. Once in their planktonic form the previously 'protected' bacteria are both detectable and amenable to conventional treatment. Future work can focus on exact parameters of minimum energy needed to disrupt a specific area of biofilm and which settings are optimal for biofilm disruption.

9. Conclusion

A Q-switch laser is capable of generating nonthermal mechanical energy deliverance in the form of shockwave. This pressure is much higher than acoustic pressure and also is much more precise. Biofilms attached to implantable medical devices can be fragmented and detached by shockwaves generated from a flexible 300 μ diameter fibre. This method may provide a potential solution for treating biofilm contaminated medical devices by disrupting the protected micro-organisms, converting the biofilm bacteria to its planktonic form, and thereby allowing one the ability to detect and kill the previously protected bacteria.

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Chapter 65

Transoral robotic surgery

M. Remacle, N. Matar and V. Oswal

1. Introduction

The Da Vinci surgical system (Intuitive Surgical Inc, Sunnyvale, California) has been used for malignant tumours of the oral cavity, base of tounge, pharynx and supraglottic larynx. The system conventionally uses monopolar or bipolar electrocautery which is manipulated by one of the robotic arms. However, electrocautery has deep thermal penetration and its use in the larynx may jeopardise optimum function preservation. In order to minimise deep thermal penetration, Remacle *et al*. (in publication) used the Da Vinci surgical system and the Lumenis CO_2 laser waveguide (CO_2 LWG) (Lumenis, Santa Clara, CA) in four patients. The tumours were located at the following anatomical sites: epiglottic, aryepiglottic fold, tonsil and tongue base.

2. Preoperative assessment

Preoperative assessment for suitability for Robotic surgery was carried out under general anaesthesia during the preoperative work up. The assessment consisted of placement of the appropriate retractor to verify if the patient is eligible for Transoral Robotic Surgery (TORS). Anaesthesia was with laser safe endotracheal tube.

3. Robot setting

The surgical robotic cart was positioned 30º from the operating table on the left side of the patient. Out of four arms, only three were used, one arm held a 0º endoscope, one arm held a five-mm EndoWrist® (Intuitive Surgical Inc.) Maryland atraumatic forceps and one arm held the CO_2 LWG introduced via the robotic arm introducer (Fig. 1).

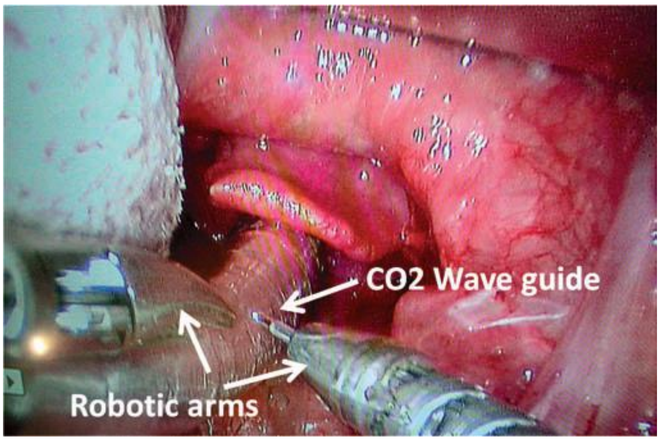

Fig 1. One robotic arm holding the CO_2 Laser Wave Guide.

4. Laser setting

The laser unit was placed at the right side of the patient. The laser parameters were set at superpulse mode, 7-15 W, continuous delivery.

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5. Flexible hollow waveguides for transmission of CO_2 laser energy

The hollow gave guide, erroneously called laser fibre, consists of a tube with a hollow core. The walls of the hollow core are lined by omnidirectional mirrors with radiation guiding mechanism (Chapter 59).

The first guide was developed by OmniGuide (Boston, MA). The OmniGuide has been successfully used in endoscopic skull base and pituitary surgery, endoscopic sinus and nasal procedures, transoral laryngeal microsurgery, treatment of tracheal stenosis, surgery for glottic and subglottic respiratory papillomas, and office-based respiratory papilloma procedures performed transnasally with flexible endoscopy.

Lumenis marketed LaserEase waveguide which is recommended for use with Acupulse CO_2 laser (Fig. 2).

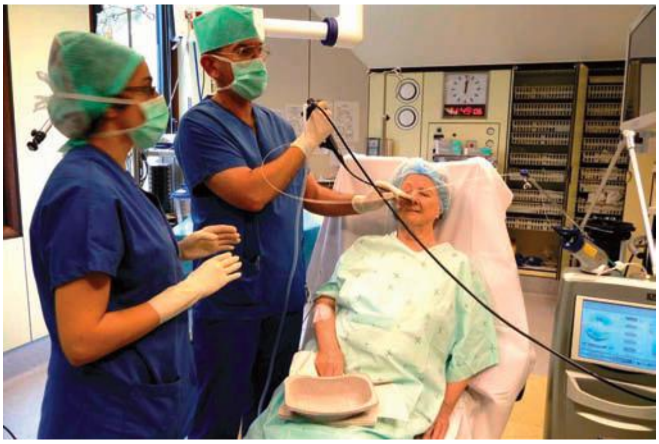

Fig. 2. LaserEase waveguide.

This waveguide has an adequate flexibility, It is mechanically robust and has a low optical loss during transmission. It has a biocompatible cladding. It also has a minimal divergence, so its energy remains adequate at near contact distance, with minimal deep thermal spread (Fig. 3).

The LaserEase waveguide is a glass tube which is coated externally with biocompatible material. The inner surface is coated with a metallic silver layer and an innermost silver iodide layer which acts as a reflective mirror. It comes in two metre length, providing easy adaptation to TORS. It has an internal core of 500 µm and outer diameter of 1040 µm. The effective spot size at the tip of the LWG is 320 µm with a minimal beam divergence, allowing working in non-contact mode at a distance of up to 15 mm. Please see Chapter 59, for further coverage of LaserEase waveguide.

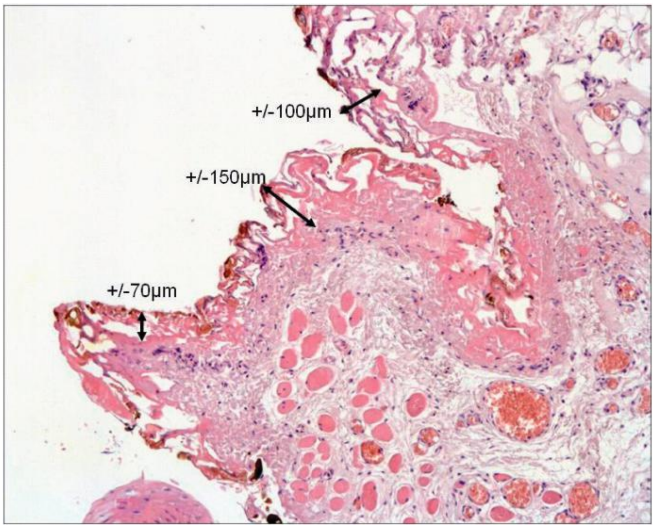

Fig. 3. Minimal deep thermal spread with LaserEase hollow wave guide.

6. Surgical team

The surgeon's console was positioned away from the patient, on the left side. At the console, the first surgeon controls the instrument arms and camera by manoeuvring the master robotic manipulators. The second surgeon was seated at the head of the patient. The video tower was on the right side of the patient. A cautery unit was connected to a coagulating suction tube handled by the second surgeon at the head of the patient.

7. Instrumentation

A double cheek retractor (Hager & Werken. Duisburg, Germany) was used to protect the patient's lips. Eye shields were also used (EMS Medical Ltd, Gloucester, United Kingdom). The patient's face was covered with moist gauze. The Laryngeal Advance Retractor System (LARS) (Fentex, Tuttlingen, Germany), specially developed for robotic surgery was used in all procedures (Remacle *et al.*, 2011). It was suspended anteriorly with a Fentex laryngoscope holder (Fentex, Tuttlingen, Germany).

For smoke aspiration, a flexible aspiration tube, with continuous aspiration, was introduced into the nasopharynx through one of the nostrils and held in

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place with an adhesive tape.

8. Tumour resection

Tumour resection followed the principles of the European Laryngological society (Chapter 11) for supraglottic Tumours. For tonsil tumours the technique used was similar to that described by Weinstein *et al*. (2007), for base of tongue tumours the technique was similar to that described by Moore *et al*. (2009). Haemostasis was achieved using the CO_2 LWG and the suction-coagulation as appropriate.

The surgical specimen was oriented on a cork plate for histological examination after formalin fixation. Additional margins from the surgical bed were taken in regions close to the tumour to assess the adequacy of tumour removal and sent for frozen-section analysis. After tumour resection, the surgical field was covered with a thin film of fibrin glue (Tissucol® Baxter, Vienna, Austria). Hematoxylin and eosin (H&E)-stained representative tissue sections were examined for histopathological analysis, to ascertain the extent of coagulation depth.

9. Postoperative care

No tracheostomy was necessary. Patients were monitored during the first 24 hours in the intensive care unit. Systemic steroids were administered for 72 hours and steroids by inhalation were advised for one week. All patients received antibiotics for one week. Feeding was done by a small nasogastric feeding tube inserted during the surgery. Intensive swallowing therapy was started the day after the surgery.

10. Assessment of robotic-assisted surgical time

10.1. Time required for exposure of the surgical field

The mean time required for installation of the mouth retractor to achieve adequate exposure of the surgical field was 30 minutes, with a range of 10 to 60 minutes.

10.2. Duration of the operative segment

The mean overall surgical time was 94 minutes with a range of 60 minutes to 125 minutes.

10.3. Hospital stay

The mean hospital stay was six days (four to nine days). Oral feeding was resumed at three days (one to five days) under speech therapy control. Healing seemed quicker than electrocautery method.

11. Benefit and risk issue

There were no perceived intra-operative or postoperative risks.

12. Discussion

Until recently, TORS relied on monopolar electrocautery which resulted in a wider width of the incision line (Liboon *et al*., 1997). The free-beam CO_2 laser energy could not be used since, in the free beam mode, it was emitted 40 cm away from the target and needed to be in line of vision.

The advances in technology resulted in the development of flexible, mechanically robust, biocompatible, low optical-loss waveguide for CO_2 laser that offers reliability and power handling capacity suitable for laser surgery applications.

The availability of the CO_2 laser waveguide, made it possible to take the CO_2 laser energy to the target, via one of the robot arms.

Solares and Storme introduced its use with the da Vinci Surgical system in 2007. They successfully performed supraglottic laryngectomy for a T4 supraglottic laryngeal tumour in a 74-year-old female. Adequate exposure was achieved with the FK Laryngo-Pharyngoscope, and the tumour was resected in its entirety. The laser setting of 10 W in a continuous wave mode provided the best tissue cutting properties.

Since then, the CO_2 LWG has been used with TORS in prostatectomy with success.

FibreLase *waveguide*
The new fibrelase waveguide for the CO_2 laser is a reliable, robust tool for TORS (Remacle *et al*., 2011). Based on author's experience with series of four cases, we find that the Lumenis Fiberlase LWG

allows for a very precise cutting, with effective haemostasis of vessels 0.5 mm or less, and is strong enough to support the bending of the tip of the introducer. It does not need to be replaced during a procedure. Its tip can be renewed instantly, if required, by using a cutting pencil. It also provides a clear aiming beam that is a significant safety feature.

TORS

TORS offers the following advantages:

- The natural hand tremors are omitted.
- Gross hand movements of the operator are turned in to small movements of instruments, enhancing dexterity.
- The surgeon perceives a true perception of depth due to three-dimensional imaging of the surgical field.

By combining the the advantages of CO_2 laser, FibreLase waveguide and TORS, it is possible to undertake accurate resection of pharyngo-laryngeal tumours, limiting the thermal effect. Long term follow-up and comparative studies are needed to confirm the role of CO_2 LWG in TORS.

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MCQ – 65. Transoral robotic surgery

1. In transoral robotic surgery (TORS)
    a. Preoperative assessment is necessary to determine appropriate access for surgical procedure by placing retractor
    b. CO_2 laser waveguide is necessary to take the laser energy to the target via one of the robotic arms
    c. Electrocautery can be used but results in uncontrolled and therefore deeper burns
    d. Wound following electrocautery takes longer to heal
    e. All of the above

2. Amongst advantages of TORS
    a. Surgical time is reduced
    b. Setting time is minimum
    c. Hand tremors are not noticealble
    d. Gross movements are reduced to small movements
    e. Magnified 3-D image adds to the precision

3. With the current (2012) technological advance of TORS it is possible to undertake surgery for lesions in the following anatomical locations
    a. Tonsil
    b. Supraglottic
    c. Glottis and subglottis
    d. Posterior oral cavity
    e. Pharynx

4. Capital outlay for TORS
    a. Is prohibitively high for its widespread use in most hospitals
    b. Its multidisciplinary application will make it cost-effective
    c. In its current state of technology, it is a viable instruments in highly selective lesions
    d. All of the above

Chapter 66

Optical diagnostics: An update on the most commonly applied techniques in the head and neck

W. Jerjes, Z. Hamdoon, T. Upile and C. Hopper

1. Introduction

The anatomy of the head and neck is both unique and complex. However, since the oral cavity and the aero-digestive tracts are easily accessible to direct examination it is feasible that disease process can be detected at an early stage. Nevertheless, in as many as 40% of patients, the disease at presentation is already at an advanced stage (T3/T4). This is unfortunate, since, the diagnosis and management of dysplastic changes or frank malignancy at an early stage would result in favourable outcome for majority of these patients (Bagan and Scully, 2008; Warnakulasuriya, 2009). The outlook will improve even further if simple techniques were available for surveillance and early detection of malignant transformation, and, recurrence following management. It will have a positive impact not only on improving the survival rate, but also preservation of function with low morbidity and better quality of life.

Successful management of early lesions encompasses continuous monitoring for detection of recurrence. Although the standard approach is by clinical examination with surgical biopsies, optimum conditions for a meaningful follow up are not always available. Inadequacy of documentation and imaging, relative inexperience of trainee grades who are usually delegated the task of follow up, and extraordinary workload which is matched only by sparse resources are some of the factors which influence assessment of regression or progression of the disease process.

The implementation of 'diagnostic aids' can help bridge this gap. A reliable, user-friendly and less skill-dependent technique will take away the multivariate factors which currently determine the quality of monitoring.

The optical diagnostic aid provides a non-invasive and real-time diagnosis. Several aids are already in use, including brush biopsy, vital staining, molecular markers, cytology and chemiluminescence (Fedele, 2009). However several factors limit their availability and interpretation of the results requires highly trained personnel.

2. What is optical diagnostics?

Optical diagnostics 'biopsy' (optical biopsy) involves the use of light of varying wavelength to examine the suspect tissue. The optical diagnostic methods are not aimed at differentiating between normal and abnormal tissue, since this can easily be achieved by direct or endoscopic visualisation. Optical diagnosis aims to provide differentiation of areas of similar clinical characteristics, *e.g.*, dysplasia versus carcinoma in situ (Upile *et al.*, 2009; 2007; Swinson *et al.* 2006; Suhr *et al.*, 2000). Optical biopsy interrogates areas of pathology such as hyperkeratosis, inflammation, dysplasia, carcinoma *in situ* and neoplasia. Of course the technique should be minimally invasive and provide diagnosis in real time and *in vivo.*

There are a number of '*in vitro'* and 'immediate *ex vivo'* modalities in common use and they include:

- Elastic scattering spectroscopy;
- Deferential path-length spectroscopy;
- Near infrared spectroscopy;
- Raman spectroscopy;

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- Confocal spectroscopy;
- Fluorescence imaging;
- Microendoscopy;
- Optical coherence tomography (Upile *et al.*, 2009; Swinson *et al.* 2006; Suhr *et al.*, 2000).

Only a brief overview of these optical modalities is possible as 'Emerging Technology' in this chapter. A fuller bibliography is provided at the end of this chapter for further reading.

3. Elastic Scattering Spectroscopy (ESS)

3.1. Basic science

Exposure of tissue to light results in a series of absorption and scattering events. The light beam undergoes single or multiple *elastic* scattering which implies that the light returns with the same energy as the incident photons. The extent of scattering effect depends on the relationship between the wavelength of light and the particulate size.

A scattering event carries with it all the characteristics of the cellular components, which are called 'scattering centres.' These centres can be normal or pathological. Normal centres are nucleus, nucleolus, chromatin content and metabolic organelles. Pathological centres may be in the form of disorganised epithelial orientation and architecture, changes in morphology of epithelial surface texture and thickness, cell crowding, increased distance from subepithelial collagen layer, enlargement and hyperchromicity of cell nucleus, increased concentration of metabolic organelles and presence of abnormal protein packages or particles.

These cellular and sub-cellular changes are identified by using the refractive indices of the cellular components. The resultant scattered light (elastic light scattering process) is then collected and analysed by a spectrometer and a spectrum is generated (Jerjes *et al.*, 2004; 2005; Sharwani *et al.*, 2006).

3.2. The design

The light emitted by cellular and sub-cellular organelles ranges from 330 nm to 850 nm, which is within the near UV and visible part of the spectrum (Jerjes *et al.*, 2004; 2005; Sharwani *et al.* 2006). The ESS system is thus designed to cover a range of 300-900 nm and consists of a pulsed xenon arc lamp for the light source, a PC-compatible spectrometer, an optical fibre (graded-index) based probe, and a laptop computer for system control and data display.

3.3. The method

The system has a fibre-optic probe which incorporates two optical fibres, one to transmit the light into the tissue and the other for collecting scattered light. The tip of the probe is momentarily placed in direct contact with the suspected lesion and activated at the keyboard or by the foot pedal. The system takes a background measurement before firing the lamp. This is followed immediately (within-100 ms) by an ESS measurement with the pulsed lamp. The background spectrum is then subtracted from the ESS spectrum. The entire measurement processing display takes less than one second.

3.4. Clinical application

The clinical application of this emerging modality in the head and neck is still limited. Very few centres possess this technology and evidence-based research is only achieved through cohort or case-control analytic studies (Level II-2). Nevertheless three studies carried out at the UCLH Head and Neck Centre, London, showed promising results on metastatic cervical lymph nodes (immediate *ex vivo*), cancerous bony mandible (archived, *in vitro*) and dysplastic oral lesions (*in vivo*). A sensitivity and specificity indices were 98% and 68% for lymph nodes, 87% and 80% for mandible, and 72% and 75% for dysplastic oral lesions spectra (Fig. 1), (Jerjes *et al.*, 2004; 2005; Sharwani *et al.*, 2006). In a recent *in vivo* study (unpublished data) differing optical spectra (signatures) were obtained specifically with basal cell carcinoma, seborrhic keratosis, fibroepithelial polyp and intradermal nevi from 73 patients with suspicious head-and-neck skin lesions.

Muller *et al.* (2003) used ESS to compare data from normal and abnormal tissue in the oral cavity. Using histopathology as control, the accuracy for spectroscopy for normal was 91.6% and for abnormal, 97%.

An *in-vivo* study was carried out at the National Medical Laser Centre, London to detect high grade dysplasia and cancer, and to differentiate it from inflammation in Barrett's oesophagus. The results showed 92% sensitivity and 60% specificity in detecting high grade dysplasia or cancer. The differentiation from inflammatory lesion showed sensitivity and specificity of 79% (Lovat *et al.,* 2006).

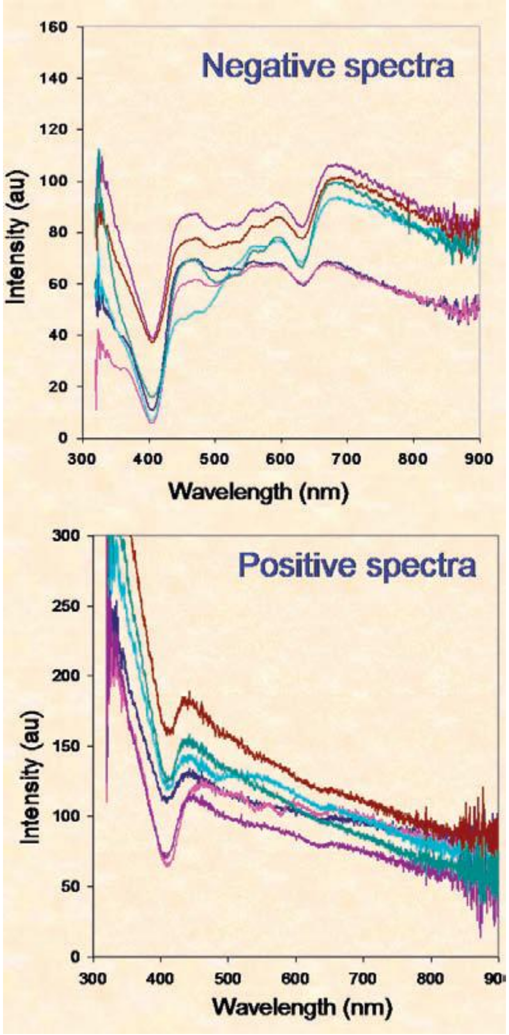

Fig. 1. ESS spectra obtained from bivalved cervical lymph nodes showing spectra acquired from histopathologically negative nodes (top) and positive ones (bottom).

3.5. Evaluation

ESS requires a close collaboration between clinicians and physicists to cleanse and normalise the spectra and interpret the algorithms. Statistical work can be difficult and time consuming. Co-registration can be a problem since optical signature reports pathology changes from just 1 mm^3 area. Therefore, with inherent 30% shrinkage due to formalin, multiple areas need to be interrogated and then compared with the 'gold standard' histopathology. However, detection of cancer in as small an area as 1 mm^3 has a merit of indicating a definitive treatment strategy. The drawback is lack of tumour margin detection which would entail treating much larger area than that detected positively.

4. Differential path-length spectroscopy (DPS)

Differential path-length spectroscopy is a minimally invasive technique able to determine intrinsic *in vivo* optical properties. This technology was developed at the Erasmus Medical Centre, Rotterdam. DPS is considered to be a form of elastic scattering spectroscopy but with fixed photon pathlength, fixed photon visitation depth and absolute measurement of absorbers (Amelink *et al.*, 2004).

4.1. Basic science

Optical pathlength of photons is constant within reasonable range of optical properties. The signal combines information about intracellular morphology, cell biochemistry (bilirubin/betacarothene) and microvascular properties (oxygen saturation and average vessel diameter).

4.2. The design

The system is a fibre-based diffuse reflection spectrometer with a tungsten-halogen lamp as a white light source. The first spectrometer uses a bifurcated fibre for illumination and collection. A second fibre carries diffusely reflected light to a second spectrometer. Each spectrometer records a spectrum with a slightly different wavelength scale. Subtraction of two measurements selects superficially scattered light.

4.3. Clinical application

DPS was used to determine the superficial optical properties of oral mucosa *in vivo* (Amelink *et al.*, 2008), bronchial tree (Bard *et al.*, 2006) and breast tissue *in vivo* (van Veen *et al.*, 2005). These studies showed that the malignant tissue at these sites was characterised by a significant decrease in microvascular oxygenation, higher blood content, significant decrease in scattering amplitude and increase in scattering slope, as compared to the normal tissue.

5. Near-infrared spectroscopy

5.1. Basic science

Near-infrared (NIR) spectrum (800-2500 nm) is currently being used in medical diagnostics, pharmaceuticals and combustion research. Absorption and transmission of NIR light in biological tissue provides information about haemoglobin concentration (*i.e.*, oxy- and deoxy-hemoglobin) (Upile *et al.*, 2009). Although NIR light penetrates deeper into tissue, compared to other modalities, molecular absorption is quite small and therefore, sensitivity is not high. Since the spectra generated from the near-infrared region depend on molecular overtone and combination vibrations, complex spectra thus generated are hard to analyse.

5.2. Clinical application

The potential role of infrared spectroscopy in biomedical science has been proposed to distinguish different biomolecules by probing chemical bond vibrations and, using these molecular and sub-molecular patterns to define and differentiate pathological from healthy samples as well as distinguishing various kinds and grades of neoplasia in human tissues (Shan *et al.*, 2008).

6. Raman spectroscopy

6.1. Basic science

Raman spectroscopy is used in physics and chemistry to study vibrational and other low-frequency modes in a system, enabling chemical characterisation and structure of molecules in a sample. It relies on inelastic scattering (loss or gain of energy) of monochromatic light, usually from a laser in the visible, near infrared or near ultraviolet range. The laser light interacts with molecular vibrations, resulting in the energy of the laser photons being shifted up or down. The shift in energy gives information about the phonon modes in the system. Raman spectroscopy is being considered as complementary or even as an alternative technique for biopsy, pathology and clinical assays in many medical technologies (Upile *et al.*, 2009; Bakker *et al.*, 2000).

Raman bands, due to biological constitutes, are generally overlapped (Raman effect), making it difficult to identify individual components correctly. Furthermore, due to the minimal sample preparation encountered in the clinical environment, biomedical samples tend to produce a strong fluorescent background which may completely obscure the true Raman signals.

6.2. Clinical application

Although Raman spectroscopy has been investigated for several decades, clinical studies in head and neck area are scant. In oncology, Raman spectroscopy is being investigated as a diagnostic tool for characterising early malignant changes.

6.2.1. Oral mucosa lesions

Using human tissues, researchers from University Hospital, Groningen, reported a study involving 37 oral mucosa lesions, showing clear variations between different cell layers (keratin/epithelium versus connective tissue layer) (de Veld *et al.*, 2005).

6.2.2. Barrett's oesophagus

Raman spectroscopy is a highly sensitive and specific technique for demonstration of biochemical changes in the carcinogenesis of Barrett's oesophagus. The Biophotonics Research Group at the Gloucestershire Royal Hospital reported several techniques to diagnose oesophageal adenocarcinoma at an earlier stage (Shetty *et al.*, 2006).

6.2.3. Diagnostics of solid tumours through a peripheral blood sample

Forty blood samples were obtained from patients with head and neck cancer and patients with respiratory illnesses, who acted as controls. Raman spectroscopy was carried out on all samples with the resulting spectra being used to build a classifier in order to distinguish between the cancer and respiratory patients' spectra. A preliminary study demonstrated the feasibility of using Raman spectroscopy in cancer screening and diagnostics of solid tumours through a peripheral blood sample (Harris *et al.*, 2009a).

6.2.4. Thyroid and parathyroid glands

Neural network analysis applied in the discrimination of human thyroid cell lines provided 95% accuracy for identification of cancerous cell lines and 92% accuracy for normal cell line (Harris *et al.*, 2009b). Detection sensitivity for parathyroid adenomas was 95% and hyperplasia was 93% (Das *et al.*, 2006).

6.3. Evaluation

The signal generated by Raman scattering is very weak and poses a diagnostic difficulty. Preliminary studies are very encouraging. Diagnostic accuracy can be complemented by combining this technology with infra or near infrared spectroscopy (see paragraph 5 above).

7. Confocal reflectance microscopy (CRM)

Confocal reflectance microscopy (CRM) is a non-invasive imaging tool enabling 'optical biopsies' of tissues at *cellular* level.

7.1. Basic science

CRM differs from a conventional microscopy in that it uses a point source of light, typically a laser, to illuminate a small spot within tissue. Backscattered (or reflected) light from the tissue is captured through an aperture, which matches the size of the illuminated spot placed in front of the detector. The aperture spatially filters light returning from out-of-focus planes within the tissue, imaging only the plane in focus. The gray-scale image created is an *optical* section representing *one* focal plane within the examined specimen.

7.2. Clinical application

This technique can supply detailed information of the epithelium 0.1-0.5 mm in depth. Since the 1980s, several investigators have shown the utility of confocal microscopy for imaging human and animal tissues *in vivo* (Webb, 1996). More recently, confocal imaging has shown stronger differentiation between nuclear and dermal contrast and improved detection of tumours. By using a contrast agent, confocal images may be collected specifically from nuclear structures with very little interference from the surrounding dermis, resulting in 1000-fold improvement in nuclear-to-dermal contrast (Gareau *et al.*, 2008).

7.2.1. Angioscopy of the retina

Confocal microscopy has to date demonstrated the most clinical utility in ophthalmology, where it has been used to image the cornea (Webb *et al.*, 1987; Mustonen *et al.*, 1998). Intravenous fluorescein is used for angiography or angioscopy of the retina and iris vasculature. After injection, fluorescein binds extensively to serum albumin in the bloodstream. The unbound contrast diffuses across capillaries, entering the tissue and staining the extracellular matrix of the surface epithelium and the lamina propria for up to 30 mins (Becker *et al.*, 2008). Cell nuclei and mucin are not stained by fluorescein and therefore appear dark. The mucosal structures that can be identified after fluorescein administration include enterocytes, cellular infiltrate, surface epithelial cells, blood vessels, and red blood cells.

7.2.2. Oropharynx epithelial changes

Confocal microscopy has been used for identifying *in vivo* cellular and intracellular changes in oropharyngeal epithelia. The most limiting factors for confocal microscopic investigation are the presence of severe hyper- and parakeratosis and extensive hyperplasia of the oral epithelium in macroscopic leukoplakia. The failure of illumination of the tissue results from the higher refractive index of keratin in comparison with cytoplasm (Brunsting and Mullaney, 1974).

8. Fluorescence imaging

8.1. Basic science

All tissues fluoresce due to the presence of fluorescent chromophores (fluorophores) within them. The fluorescence can either occur as autofluoresence (if induced by UV light), or as a laser-induced phenomenon enhanced by either topical or systemic application of 5-aminolaevulinic acid (ALA). Fluorescence spectroscopy can detect these substances and provide characteristic spectra that reflect biochemical changes occurring within the tissue (Upile *et al.*, 2007; 2009). Commercially available fluorescence imaging equipment aims at highlighting malignant tissue, especially where it is not evident under white light in a large field of view.

An optical endoscope can be used for both illumination and detection of the tissue fluorescence. The images are captured by a frame-grabber fitted with an analogue/digital converter (ADC) and analysed and displayed on a personal computer loaded with software (Upile *et al.*, 2007; 2009)(Fig. 2).

8.2. Clinical application – larynx

At Ludwig Maximilian University, Munich, a great deal of work has been undertaken using autofluorescence laryngoscopy, and 5-ALA laryngoscopy. In a prospective study (Arens *et al.*, 2007), both autofluorescence laryngoscopy, and 5-ALA laryngoscopy was undertaken in 56 patients with pre-

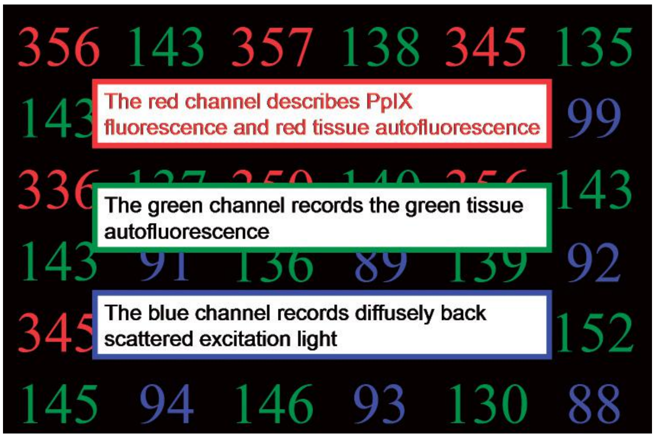
356 143 357 138 345 135
143
The red channel describes PpIX fluorescence and red tissue autofluorescence
99
336
143
The green channel records the green tissue autofluorescence
143 91 136 89 139 92
345
The blue channel records diffusely back scattered excitation light
152
145 94 146 93 130 88

Fig. 2. Magnified pixel colour fluorescence intensity values.

cancerous and cancerous lesions of the cord. They reported the following results.

8.2.1. Normal mucosa
During autofluorescence endoscopy, normal laryngeal mucosa presented a typical green fluorescence signal, which turned blue during 5-ALA-laryngoscopy.

8.2.2. Benign and precancerous or cancerous lesions
Both imaging techniques were suitable to distinguish benign from precancerous or cancerous lesions. Fluorescence was absent during autofluorescence endoscopy for precancerous and cancerous lesions, whereas increased protoporphyrin IX fluorescence (PPIX) was noted during 5-ALA laryngoscopy.

8.2.3. Scarred vocal folds
PPIX fluorescence was easily recognised in scarred vocal folds.

8.2.4. Early and recurrent cancer
Both autofluorescence and 5-ALA-induced PPIX imaging techniques are useful in the early diagnosis of laryngeal cancer. Moreover autofluorescence can be used immediately without drug application and possible side effects. 5-ALA-induced fluorescence seems to be more suited for diagnostic examination of mucosal lesions in recurrent precancerous and cancerous lesions after surgery.

8.3. Clinical application – oral cavity

Several studies at the MD Anderson Cancer Center, Houston found differences in spectra from normal, dysplastic, and malignant oral mucosa (Heintzelman *et al.*, 2000; Gillenwater *et al.,* 1998).

At UCLH Head and Neck Centre, London a study was undertaken for fluorescence imaging with the topical application of 5-aminolevulinic as mouth rinse in 71 patients who presented with clinically suspicious oral leukoplakia. A sensitivity of 83-90% and specificity of 79-89% were obtained between normal and dysplastic lesions (Sharwani *et al.*, 2006).

University Hospital Groningen researchers recorded autofluorescence spectra in 96 volunteers with no clinically observable oral lesions. Skin colour strongly affected autofluorescence intensity. Gender differences were found in blood absorption. Alcohol consumption was associated with porphyrin-like peaks. However, all differences apart from those associated with skin colour were of the same order of magnitude as standard deviations within categories (de Veld *et al.*, 2004).

9. Micro-endoscopy

9.1. Basic science

Micro-endoscopy involves examining tissue *in situ* at a magnification from 60x to 1000x. At this magnification, details of tissues, cells and cellular ultrastructures can also be observed to detect specific patterns for pathology, *e.g.*, inflammation, metaplasia, dysplasia, and malignancy.

The Storz Hopkins II auto-clavable micro-endoscope is attached to a camera system linked via a video recorder with outputs to a monitor and photo-printer. The scope is available in different sizes which can be used for different anatomical sites; the dimensions of the micro-endoscope are 5.5 mm diameter and 23 cm long, the vital stain that can be used here is Methylene blue (Fig. 3).

9.2. Clinical application

As against frozen section biopsy, the micro-endoscope provides a real time magnification at examination and can be used to guide further surgery, biopsy or simple surveillance of large areas of suspect mucosa. A recent study at Rice University, Houston evaluated micro-endoscopic imaging to identify neoplastic lesions in patients with Barrett's esophagus. Subjective analysis of the images by expert clinicians achieved average sensitivity and specificity of 87% and 61%, respectively (Muldoon *et al.*, 2010).

The main application with the scope is that we can have a more informed assessment of the state of the *in situ* epithelial margin when excising squamous cell carcinoma. Combined with the recent advance of vital or immunologically tagged antibody targeted staining, microendoscopy will enable histopathological assessment of the surgical margin as against the standard clinically assessed margin. The extension of this technology to the management of glottic cancer will obviously have a great impact for the preservation of the voice quality with 'endoscopically assessed' clear histological margin in real time.

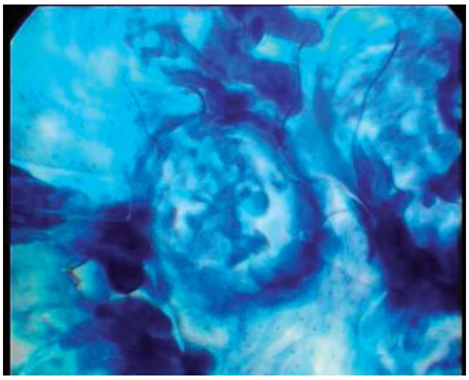

Fig. 3. Micro-endoscopic assessment of the tongue showing the surface view of a taste bud, with the nuclei and cell borders outlined by methylene blue dye. The mucosa is normal in appearance.

10. Optical Coherence Tomography

Optical coherence tomography (OCT) uses light to determine cross-sectional anatomy in turbid media such as living tissues. OCT is analogous to ultrasound imaging except that it uses light rather than sound. The high spatial resolution of OCT enables non-invasive *in vivo* 'optical biopsy' and provides immediate and localised diagnostic information (Huang *et al.*, 1991).

10.1. Basic science

OCT images are formed by dividing light from an optical source into two paths, one of which is directed to the tissue sample, and the other to a reference mirror. Light reflected from the sample is recombined with light from the reference mirror and detected, forming an interference signal only when the lengths of the sample and reference paths are matched to within a short distance termed the coherence length of the light source.

10.2. Clinical application

OCT has been applied in the head & neck, especially in the nasopharynx, oropharynx, and larynx in an attempt to detect areas of inflammation, dysplasia and cancer.

10.2.1. Malignancy of larynx

Beckman Laser Institute and Medical Clinic, University of California, Irvine undertook clinical studies in laryngeal pathology. OCT was coupled to a surgical microscope, allowing hands-free OCT simultaneously with visualisation of the vocal cords (Vokes *et al.*, 2008; Rubinstein *et al.*, 2010) to distinguish benign lesions from micro-invasive cancer that has violated the integrity of the basement membrane (BM) (Wong *et al.*, 2005). This technology has yet to deliver the promise of the recognition of basement membrane to detect its invasion by malignancy.

10.2.2. Oral lesions

OCT has been used at the University College Hospital, London, in 27 patients with suspicious oral lesions to assess changes in keratin, epithelial, subepithelial layers and identification of the basement membrane in patients. The acquired OCT data were then compared with histopathology results. This pilot study confirmed the feasibility of using OCT to identify architectural changes in pathological tissues (Jerjes *et al.*, 2010). Further unpublished data indicates the feasibility of OCT in assessing oral and skin resection margins in clinical setting in the very near future (Fig. 4).

11. Discussion

Optical diagnostics provides non-invasive techniques that will allow improved surgical decision making with better appreciation by the clinician of the histopathological natural history of the disease. These novel technologies will also drive improved image and evidence based medical education with better documentation and audit, allowing informed clinical choices whilst operating. It would also facilitate targeted training and education in their usage and dissemination of its applications to virtually any discipline in medicine, surgery or dental practice.

Benefits to the patients are evident. Rather than having all suspicious areas excised for histopatho-

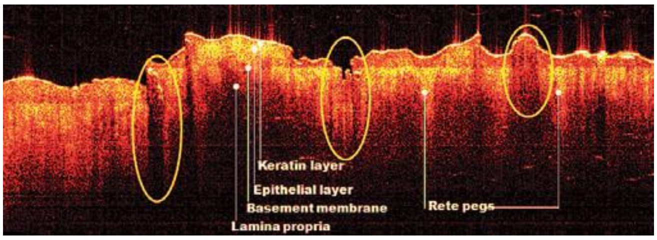

Fig. 4. OCT image showing multi-focal oral tumour. There is clear loss of definition and invasion shown by the vertical streaks in the circled areas. The basement membrane is breached, and there is significant loss of definition of all cellular layers.

logical confirmation, only those areas which are optically proven to be suspicious will be biopsied. This will lead to reduced workload for the labs and there will be an increased positive yield, with significant resource implications.

Optically-directed excision may allow more complete disease treatment thus reducing the rate of recurrent or residual disease. The costs of a failed surgical margin are considerable in terms of increased morbidity and mortality with a halving of patients' survival, resulting in increased costs of adjuvant therapies and major revision surgery which inevitably lead to increased morbidity.

We anticipate the future publication of libraries of normative and pathological data to act as a standard clinical reference. This will enable the practitioner to use these validated technologies to help them in their day-to-day clinical work. We would predict that the practitioner would eventually be able to determine the diagnosis immediately by looking at the image on the screen. The technologies would, for a small initial outlay, provide the means to accurately diagnose a range of benign, malignant and infective conditions.

12. Conclusions

Optical diagnosis of the head and neck is a rapidly evolving area of clinical research that can be readily translated to enhance patient treatment and overall quality of life. Much still needs to be achieved and granting organisations are solicited to pay attention to this specialty where relatively small investments may lead to enormous dividends in terms of improvements in treatments throughout the fields of medicine, surgery and dentistry.

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MCQ – 66. Optical diagnostics

1. Optical diagnostics
    a. Is a non-invasive method to monitor recurrence of disease by using exposure of light at varying wavelengths on to the suspect target tissue
    b. Establishes the presence of diseased tissue as against normal tissue
    c. Differentiates tissues in areas of similar clinical characteristics
    d. Provides real time and in vivo diagnosis which is cost effective
    e. Provides all of the above

2. Optical diagnostics involves
    a. Application of sensitiser such as methylene blue and visualisation with white light
    b. Visualisation of suspect tissue with light of varying wavelengths
    c. Identifying normal from abnormal tissue
    d. Identifying tissues of similar clinical characteristics
    e. Both in vitro and in vivo applications

3. Elastic Scattering Spectroscopy
    a. Is based on absorption and scattering of light by the tissue at the cellular level
    b. It is applicable only for tissue which have a high content of elastic fibres
    c. Since the interrogated tissue sample is extremely small, it is necessary to undertake readings from multiple areas
    d. The technique is useful in identifying clear margin and thus complete clearance of the pathological tissue
    e. It does not require high tech set up

4. Elastic Scattering Spectroscopy (ESS) involves
    a. Exposure of tissue to light
    b. Measurement of degree of scatter for elastic tissue such as collagen
    c. Measurement of scattering event within the tissue
    d. Measurement of scatter from scattering centres within the cells
    e. Measurement of scatter from normal as against pathological scatter centres of the cellular components

5. Differential path-length spectroscopy (DPS)
    a. Is a form of ESS but with a fixed photon path-length
    b. Similar to ESS, it measures scatter from scattering centres of the cells
    c. Is based on a relatively constant path-length of photons
    d. Is useful to determine microvascular properties of the tissue
    e. All of the above

6. Differential path-length spectroscopy detects malignancy due to
    a. High mitotic activity at cellular level
    b. A significant decrease in microvascular oxygenation
    c. Formation of neovascularisation
    d. Significant decrease in scattering amplitude
    e. Increase in scattering slope

7. Raman spectroscopy
    a. Is used to study vibrational and other low-frequency modes in a system, enabling chemical characterisation and structure of molecules in a sample

   b. 'Raman effect' is intense and specific in a peripheral blood sample and provides diagnosis of early malignancy in Barretts's oesophagus
   c. The signal generated by Raman scattering is very weak and poses a diagnostic difficulty
   d. Raman spectroscopy is a highly sensitive and specific technique for demonstration of biochemical changes in the carcinogenesis of Barrett's oesophagus
   e. Raman spectroscopy is feasible in cancer screening and diagnostics of solid tumours through a peripheral blood sample

8. Confocal reflectance microscopy
   a. Provides information of tissue characteristics at various planes
   b. Uses a laser light to illuminate a small spot within tissue thus giving detailed information of the epithelium 0.1-0.5 mm in depth
   c. This technique is used widely in angioscopy of the retina to examine the circulation of retina and choroid
   d. A high refractive index of keratin serves as a useful marker in hyperkeratosis of larynx, providing a useful method to diagnose a malignant change
   e. Confocal reflectance microscopy is used for examining the extent of cataract affecting the lens structure

9. Fluorescence imaging
   a. Fluorescence can occur as auto-fluorescence when induced by UV light spectroscopy
   b. It produces characteristic spectra that reflect biochemical changes occurring within the tissue, not evident under white light in a large field of view
   c. In auto-fluorescence laryngoscopy, fluorescence is absent during auto-fluorescence endoscopy for precancerous and cancerous lesions
   d. Administration of protoporphyrin IX increases fluorescence during 5-ALA laryngoscopy
   e. All of the above

10. Micro-endoscopy
   a. Is undertaken at a magnification ranging from 60x to 1000x
   b. It is used to detect lymphatic micro-invasion in malignancy
   c. Intra-operatively, it can be used to assess the margins and support specific frozen section assessment as against the one which relies on clinical judgement
   d. It is thus a tissue preservation technique, much useful for glottic cancer to preserve useful function
   e. All of the above

11. Optical Coherence Tomography (OCT)
   a. Optical Coherence Tomography is analogous to micro-endoscopy
   b. Light reflected from the sample is combined with light from the reference mirror and matched to within a short distance termed the coherence length
   c. OCT enables non-invasive in vivo 'optical biopsy' and provides immediate and localized diagnostic information
   d. OCT has been used to distinguish benign lesions from micro-invasive cancer that has violated the integrity of the basement membrane
   e. All of the above

12. Optical diagnostics has a potential
   a. To replace the conventional biopsy for diagnosis
   b. Screen the lesions so that the conventional biopsy is more accurately targeted.
   c. To confirm the result of conventional biopsy
   d. To be cost effective due to non-invasive nature of tissue sampling
   e. Undertake intra-operative examination of the margin for minimum tissue removal and maximum function preservation

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Chapter 67

Photochemical internalisation

W. Jerjes* and C. Hopper

1. Introduction

Tissue-specific targeting is often limited due to inefficient transfer of macromolecules, *e.g.*, in gene therapy, to the cytosol from their entrapment in endocytic vesicles. Berg *et al.* (1999) examined the possibility of *photochemically* damaging the endocytic vesicles and thus releasing macromolecules into the cytosol. This novel technique is termed 'Photochemical Internalisation' (PCI) and opens up the possibility of tissue-specific targeting for cancer therapy, gene therapy and vaccination.

2. Literature review

In 2001, the same group documented the *in-vivo* approach to site-specific cancer therapy via PCI. Female nude mice with subcutaneously growing human adenocarcinoma were used as tumour models. Forty-eight hours prior to light exposure, the photosensitiser aluminum phthalocyanine disulfonate was administered intraperitoneally. Six hours before light exposure a single dose of 50 microgram of gelonin was administrated *intratumourally*. The tumour was then exposed to 135J/cm^2 of direct red light. The study revealed synergistic effect of photoactivation of photosensitiser and gelonin and the resultant PCI reaction (Selbo *et al.*, 2001).

Bleomycin is used in several standard cancer chemotherapy regimens. However, its hydrophilic and relatively large chemical structure limits its ability to penetrate membrane structures resulting in the accumulation of bleomycin in endocytic vesicles (Berg *et al.*, 2005). Berg *et al.* (2005) evaluated the therapeutic potential of aluminum phthalocyanine disulfonate (AlPcS2a)-based photochemical delivery of bleomycin to three tumours of different origins, introduced subcutaneously in mice. The results showed delayed tumour regrowth and 60% complete response in two out of three tumour models. When compared to bleomycin alone, no complete response was achieved in any tumour model.

Multiple-drug resistance is an expected risk in clinical oncology. Authorities describe acidification of endocytic vesicles and increase in cytosol pH as one of the most common causes for resistance. This, usually, leads to trapped chemo-active agents in endocytic vesicles and eventually phenotypic drug resistance. A recent study by Lou *et al.* (2006) has proven that PCI reverses doxorubicin resistance in breast cancer cells.

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*Dr Waseem Khalid Wadee Jerjes has been actively involved in the management of the majority of the above patients in this phase-I clinical trial. Also, he was fully involved in carrying out all clinical and laboratory procedures for the majority of the patients. The presented data (of the 11 patients) is part of his MD project in Clinical Research at the Department of Surgery, University College London Medical School, London, United Kingdom.

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3. Amphinex-bleomycin PCI trial at University College Hospitals, London, UK

This is an ongoing trial.

3.1. Aims and objectives

The aim was to evaluate the safety and tolerance of amphinex (a new photosensitising agent). Secondarily, the trial was designed to identify and/or evaluate any toxic or immune-modulating events related to amphinx-bleomycin PCI and to study the drug pharmacokinetics. Although efficacy was not a primary end point in this study, PCI anti-tumour activity was also documented.

3.2. Target patients

Fourteen patients were recruited at the Oral and Maxillofacial/Head and Neck Centre, University College Hospitals NHS Foundation Trust, London to participate in the first phase I clinical *dose-escalation* trial of photochemical internalisation (PCI) using Amphinex® (PCI Biotech) with Bleomycin as the chemotherapeutic agent.

The target patients were those with locally recurrent or advanced/metastatic, cutaneous or mucosal malignancy. These cases represent one of the most difficult tumours to treat, namely, osteosarcoma and squamous cell carcinomas of the head and neck and the chest.

3.3. Method

Patients were initially screened (day minus 14) for eligibility by the oral and maxillofacial /head and neck surgeon and the oncologist. The inclusion/exclusion criteria were discussed and the patients were provided with an information sheet explaining the study and the level of patient participation, in non-scientific terms. Patients were clinically assessed as eligible for bleomycin and had a predicted life expectancy of at least three months. No other intervention was to be carried out in the first 28 days from enrolment, Skin type was I-IV (Fitzpatrick skin classification), and performance status of 0-2 (Eastern Cooperative Oncology Group (ECOG) Scale). Amphinex was administered prior to bleomycin infusion and subsequent illumination with a diode laser. Fourteen patients in this trial received 0.25-1.5mg/kg amphinex (day 0) approximately 93 hours prior to a slow bleomycin infusion (15000 u/m^2). The tumour surface and two to three mm of margin was illuminated with diode laser emitting at 652 nm, on day four (96 hrs). The power setting was 60J/cm^2 delivered at an irradiance of 100 mW/cm^2 over 600 seconds. Subsequent patients received escalating doses of amphinex (*i.e.*, 0.5 mg/kg, 1.0 mg/kg and 1.5 mg/kg) with no change in the bleomycin dose. The aim is to achieve the maximal tolerated dose (MTD) of amphinex. The discontinuation of a patient from the study occurred in the event of disease progression or dose-limiting toxicity (DLT).

3.4. Patients monitoring

Patients monitoring and follow up started from day minus 14 and continued to day 28, and up to three months where indicated. The drug safety and tolerance were assessed by measuring the concentration (PK) of amphinex in plasma and urine after centrifugation and samples freezing under -20^{o}C. Routine blood monitoring was undertaken to detect any possible adverse events to the vital organs and bone marrow. Patients were also monitored very carefully and vital signs were regularly registered. Further examinations, investigations and medical interventions were considered as and when indicated.

Visual analogue scale (VAS) was used to assess pain immediately and 24 hours after illumination. Assessment of amphinex accumulation in the skin was performed by fluorescence spectroscopy at 670 nm on regular basis. Skin-sensitivity testing is conducted using white light with a luminance of 500 lux and/or 50,000 lux. These illuminances are equivalent to indoor light and bright sunlight, respectively. Clinical photography is performed at one hour and 24 hours post skin sensitivity testing.

3.5. Assessment of PCI anti-tumour activity

Assessment of PCI anti-tumour activity is carried out using clinical photography due to the fine tumour thickness. Ultrasonography is acquired when indicated. The disappearance of the target lesion(s) for four weeks was considered a complete response. Other tumour response definitions include: partial response (at least a 30% decrease in the sum of the longest diameter), stable and progressive disease. Response was assessed at day 28.

3.6. Adverse events

An assessment of all adverse events experienced since the treatment visit are reported immediately. Adverse events were followed until resolved. Blood sampling to check standard blood biochemistry and vital signs was performed. Fluorescence and skin photosensitivity was measured and followed until values returned to normality.

4. Discussion and conclusion

At the time of writing, the trial is ongoing. The initial clinical findings are discussed below.

This study shows that at the current doses (1.0-1.5 mg/kg), amphinex appears to be safe and well tolerated. This was borne out by the lack of side effects and lack of phototoxicity. We recognise that this is the first reported ongoing human study on our first fourteen patients, however, because the clinical responses were so unexpected and impressive, we felt compelled to present our data to date. There is clear scientific evidence that PCI is a clinically relevant technique that has a huge potential in the treatment of tumours that are resistant to chemotherapy. We are currently consolidating the amphinex 'dose' in this study and we anticipate completion of this study in 2013.

4.1. General considerations

For all patients, a pre-treatment eye exam was unremarkable. No immediate clinical symptoms were reported prior to amphinex administration and no immediate drug adverse events were identified. Vital signs were all within normal clinical range. Haematological and biochemical laboratory measurements did not show significant change that would warrant an intervention. No direct drug adverse events were recorded (including light sensitivity and/or reaction).

4.2. Unexpected anti-tumour activity

The most striking finding from this small ongoing phase-I clinical trial is the dramatic tumour responses. The starting dose of amphinex for the study was set at a level not expected to trigger a PCI response, however, there appeared to be a localised synergistic effect with photo-activation. This effect was not confined to squamous cell carcinoma, but was noted also on tumours, such as sarcoma, which have traditionally been very resistant to most treatment modalities.

4.3. Unexpected intra-operative pain

The only real issue to date is a high level of peri-treatment pain in patients receiving PCI under local anaesthesia. This may be related to the high level of tumour cell death. We have used general anaesthesia and sedation and found that patients report less peri-treatment pain. Post-treatment pain seems to subside quite quickly, irrespective to the mode of anaesthesia.

The pain was localised to the site of the cancer. The pain appeared to be correlated with completeness of tumour cell killing (clinical response). The induction of acute necrosis with the release of intracellular degradation products may have stimulated small pain fibres either directly or through histamine release. It has been found that in laboratory models, the use of antihistamines reduced the efficacy of amphinex.

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MCQ – 67. Photochemical internalisation

1. Tissue-specific targeting
    a. Is limited due to impervious cell membrane
    b. Can be limited due to their entrapment in endocytic vesicles
    c. Due to antibodies in the cell membrane
    d. Due to low concentration at the cell membrane in avascular tissue
    e. All of the above

2. Photochemical internalisation is a term used for
    a. Altering the properties of therapeutic material with laser light so that it is transferred in to the cell cytosol
    b. Damaging the endocytic vesicles with laser light so that micromolecules can be released in to the cell cytosol
    c. Therapy where laser is used to activate photosensitiser *in vivo*
    d. Treatment which involves photodynamic therapy

3. Photochemical internalisation is based on
    a. Use of nano particles
    b. Exposure of tissue to a specific laser wavelength
    c. Photodynamic therapy
    d. Photochemically damaging the endocytic vesicles and thus releasing macromolecules into the cytosol
    e. Chemotherapeutic reaction by administration of specific cytotoxic drugs

4. Amphinex
    a. Is a new photosensitiser
    b. It is administered concurrently with bleomycin
    c. It is administered prior to slow infusion of bleomycin
    d. It is activated with exposure to diode laser
    e. It overcomes the tumour-resistance to cytotoxic drugs

5. Synergistic action of amphinex-bleomycin administration has following features:
    a. There is increased photosensitisation
    b. There is severe perioperative pain
    c. The pain is correlated with completeness of tumour cell killing (clinical response)
    d. There is no tumour regression
    e. There are no direct drug adverse events (including light sensitivity and/or reaction)

6. Adverse effects include
    a. Skin sensitisation
    b. Gross tissue necrosis
    c. Peri-treatment pain
    d. Alteration in blood chemistry

Section XII: Appendices

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Appendix I

Core of Knowledge

H. Moseley

Editors' note:
Any scientific knowledge has the very basic structure upon which the various applications are formulated and laser science is no exception. This publication has given a generous six-chapter coverage to the basic laser science in Section I, around which the various clinical applications have evolved.

Attending dedicated courses has the merit of condensed learning. Professor Moseley has done much to take lead, design and conduct such courses in a number of countries. Here we reproduce a set of headings suitable for constructing courses, for the prospective organisers.

Core of Knowledge

Core of Knowledge represents a body of knowledge that underpins the safe use of lasers in clinical practice. It is intended to be undertaken by all staff using laser (class 3 and 4) and non-laser (IPL and LED) light sources in a range of applications, including medical, surgical, dental and aesthetic practices.

Its aim is to provide users with an understanding of the basic principles of laser safety. It is essential that Core of Knowledge is supplemented by additional training in specific applications. Although exact content may differ slightly, the following syllabus is considered to be the minimum course content that may be covered by training centres. Course duration should total at least three hours. After attending the course, each participant should understand

– the basic principles of laser generation and review of laser/IPL technology;
– the laser hazard classification;
– the meaning of associated warning labels;
– the principles of quality assurance;
– the emission characteristics of different types of equipment;
– the laser-tissue interaction mechanisms;
– the penetration of light of different wavelengths through skin and eye;
– the dangers of central versus peripheral retinal damage;
– the hazards to eye and skin from accidental exposure;
– the principles of risk assessment;
– the laser safety management including the role of the Laser Protection Adviser, Laser Protection Supervisor, Local Rules and Controlled Area;
– the risks associated with accidental reflections;
– the personal protection measures including eye protection;
– the concept of Maximum Permissible Exposure and Nominal Ocular Hazard Distance;
– the hazards to the patient including endotracheal tube ignition;
– the incidental hazards, including electrical, fire explosion and plume emission;
– the relevant legislation, standards and guidelines;
– how to deal with an adverse event or accidental exposure.

Course organisers should issue an attendance certificate and keep a record of attendees for a

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minimum of five years. There is merit in performing an assessment of understanding.

It is good practice for individuals to re-attend Core of Knowledge courses every five years, or sooner following an extended absence or if there have been significant changes to equipment or practices affecting the individual.

It is recommended that the course should have an accreditation for its educational merit by a professional body such as the British Medical Laser Association.

Professor H. Moseley
President, British Medical Laser Association
Member, Executive Council, European Laser Association

Appendix II

Optical radiation: Local rules

S. Wharmby and V. Oswal

1. Definition and scope

Local rules are a set of protocols, drawn within the framework of the institutional laser policy, which in turn is mandated by the statutory Health and Safety at Work or some such article, enacted state-wise or nationally. As a general guide,

- Identify the target readership and the key safety points.
- Where possible, aim to cover all rooms and lasers into a single document.
- Aim to standardise the controls. For example whilst it is not strictly necessary to cover windows for CO_2 lasers, it may be less confusing to include this as a universal practice.
- Ensure that understanding is checked rather than ask staff to just read and sign.
- Use plain everyday conversational language and avoid specialist terminology and acronyms as much as possible.
- Set a date for future review of protocol. Should there be any change in the current equipment or practice, a re-evaluation should take place directly after the change, before its next schedule.

2. Location

The laser activity area is identified as *laser-controlled area (LCA)* where all laser activity is to take place. The laser activity includes testing equipment, its therapeutic use and its shut down. Only authorised personnel are entitled to enter the LCA during laser activity. The area is clearly marked with appropriate illuminated signage.

3. Laser log

All the lasers in use in the LCA and their class are recorded. Periodic equipment inspection, calibration and user-maintenance schedules are recorded. Manufacturers' maintenance schedule or contracted maintenance schedule is also recorded. Plume evacuator maintenance is required as per manufacturers' instructions.

4. Laser personnel

A list of named individuals and their designation is maintained and updated as required.

- Laser safety officer (or technician): responsible for laser equipment and its safe use.
- Laser protection adviser (risk assessor): responsible for risk assessment and protection measures based on risk assessment.
- Laser operator: He or she is trained in the therapeutic use of the laser and is ultimately responsible for all aspects of laser activity.

5. Training requirements for designated laser personnel

Set out minimum training requirements for the proposed laser activity. A named individual is to be responsible for overseeing compliance.

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6. Procedures

6.1. Pre-activity (start-up) check-up

- Warning signage: illuminated when laser activity is taking place.
- Availability of Personal Protective Equipment (PPE) at the entrance door.
- Interlocking door on laser activation, and covering windows with screens.
- Key holders: Named personnel as authorised key holders.
- Calibration check, alignment, provision of dedicated safety glasses, equipment check-up, anaesthetic check-up for laser safe anaesthetic tracheal tubes, etc.
- Check alignment, where appropriate.
- Fibre preparation and check, where applicable.

6.2. Intra-activity procedure

- Operation of control panel.
- Foot pedal activated only by the laser operator and only when the beam is on the target.
- Monitor-visualisation of laser operations/procedures by staff other than the laser user.
- Ensure that the general noise level is kept to a minimum since laser equipment in action does generate substantial noise which may interfere with hearing important, work related conversation.
- Position the control panel in such a way that it remains in sight of the laser operator, for personally checking the parameters.

7. Post-activity (shut-down) procedure

- Shut down.
- Maintenance.
- Storage.

8. Protection measures

These are based on risk assessment, *e.g.*, protective eyewear, laser-safe anaesthetic tracheal tube, etc.

9. Contingency plan

In the event of adverse incidence, a plan should be in place, similar to the adverse incident procedure generally adopted by the institution.

- To minimise the hazard (*e.g.*, instantly remove burning material), instigate support procedure.
- Transfer to an appropriate facility (icu, ophthalmic department for eye injury).
- Inform next of kin, authorities and defence organisations.
- Create contemporary records.

10. Emergency plan

Emergency beam and non-beam hazard management procedures should be outlined in local rules (*e.g.*, fire drill).

Appendix III

Glossary

S. Wharmby and V. Oswal

The application of laser energy represents a high degree of teamwork. Standardisation of terminology for communication within the team in noisy and busy operating schedules is vital. The authors hope that all the members of the laser team will be encouraged to read the glossary so that a common communication platform is established for a safe and efficient working environment.

The various nomenclatures and their working definition provided here, are meant primarily for the clinician's day to day practice in laser technology. The list is neither complete, nor is it meant to represent scientific accuracy of laser physics. It is not a substitute for reading the various chapters in this book with their extensive references. Some of the terminology may vary from country to country, or even within the country, from one laser centre to another laser centre.

Ablation

The removal of tissue by vaporising it layer by layer, using laser energy. *See also* Tissue ablation.

Absorption of laser energy

The term absorption refers to the physical process of absorbing light. All incident light or a laser beam is not absorbed since, some is lost to scatter or reflection. The loss of light is termed 'attenuance'. The proportion of absorbed light and attenuance of any specific wavelength depends on the material through which it passes. For example, the CO_2 laser wavelength is maximally absorbed by water and is converted into heat. Therefore, the thermal effects of CO_2 laser are maximal in mucosa, which has high water content. In otolaryngology, most lesions are mucosal and thus the CO_2 laser is the most effective laser for surgical procedures.

The extent of absorption of energy by water is expressed as water coefficient for that particular laser. Er:YAG laser has highest water absorption coefficient. Nd:YAG laser, on the other hand, has a poor water absorption coefficient.

Experiment: Strike CO_2 laser beam on the surface of the water in a container and notice instant vapour formation. Strike the beam on to an ice cube. Immediate vaporisation forms a substantial pit at the striking point.

Absorption length

Absorption length is the extent of tissue penetration by laser energy. The term 'length' does not strictly represent a linear penetration since the penetrated energy undergoes a change of direction due to internal reflections. The phenomenon is known as scatter (q.v.), and varies a great deal with the type of wavelength used and the tissue composition. Penetration of the laser beam is synonymous with the absorption length. Since the CO_2 laser is maximally absorbed by the water content of the mucosa, most of its energy is spent at the surface. Very little energy is conducted into the deeper tissue. Therefore, the depth of penetration of the CO_2 laser is very shallow. On the other hand, Nd:YAG laser has an inherent high scatter within the tissue when used in near-contact mode, so its penetration is deeper.

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Acceptance angle
Maximum angle of incidence at which the fibre transmits light with total internal reflections.

Acuspot
The diameter of the spot in acu-spot varies according to the focal distance. The diameter is 250µ for a focal distance of 400mm (laryngology) and 150µ for a focal distance of 200mm (otology). At 10 watt power, therefore, the energy delivered by a 150µ spot is *greater* than that delivered by a 250µ spot. Use of acu-spot enables the surgeon to undertake precise surgery, with comparatively low power settings to minimise the thermal damage zone.

Aiming beam
This is typically a low-power visible laser, superimposed on the path of the therapeutic beam.

Angiolytic lasers
See selective photothermolysis.

Attenuation
Reduction in energy as the laser light passes through a medium. Attenuation is due to absorption, scatter and conduction.

Attenuation coefficient
The attenuation coefficient is a quantity that expresses how easily a material or medium can be penetrated by a beam of light. A large attenuation coefficient weakens the beam as it passes through that medium. Water, which absorbs the CO_2 laser wavelength, has a high attenuation coefficient.

Autofluorescence
Some biological substances, such as mitochondria, emit light 'naturally' when they absorb the incident light. This property is known as autofluorescence. On the other hand, other substances need addition of chemicals known as fluorescent markers or fluorophores in order to get them to emit light.

Average power (Pav)
The total power delivered, averaged over time.

Biofilms
Biofilms are clusters of bacteria that reside in a self-retaining surface adhering extracellular polymeric slime (EPS) matrix. Biofilms show a phenotypic resistance to antibiotics which are active against the same bacteria when in planktonic form.

Calibration
When the devices get older or in case there is a malfunction, the actual output at the delivery port may not correspond to the nominal output shown on the console of the machine. The laser machine typically requires regular servicing by an engineer. A practical way of ensuring peak performance of the laser is to test-fire a perspex block (Chapter 5, Fig. 2) and to note the date of testing. Serial tests are carried out periodically, compared with the initial result, and stored. Any loss of power indicates that service is required before the scheduled date.

Calorie
A calorie is a unit of energy. One calorie (symbol: cal) is the amount of energy needed to increase the temperature of one gram of water at 15ºC by 1 kelvin at standard atmospheric pressure. One calorie equates to approximately 4.2 joules.

Carbonisation
Carbonisation is a result of inefficient vaporisation of the tissue by laser energy. It is seen as a zone of carbonised tissue in the ulcer crater following vaporisation of tissue. Carbonisation of tissue is an unwanted effect. Carbonised (charred) tissue burns at a much higher temperature than the boiling point of water (100ºC). Continuing laser strikes on the tissue covered with char results in gross heating of the surrounding tissue which suffers extensive thermal damage well beyond the intended target. Removal of charred layer by wiping it with wet gauze is an integral part of every laser surgical technique. In CO_2 laser surgery, charring is minimised by using the laser in superpulse mode. The high average power of short exposure pulses results in maximum vaporisation and minimum carbonisation.

Cartilage reshaping
The cartilage is first deformed to the desired shape using a jig, which consequently produces stress in the regions of applied force. These areas of stress are irradiated using laser energy in order to induce mechanical relaxation and thus minimise the inherent forces within the cartilage that resist the new configuration. After a period, the jig is removed and the new shape is maintained. For reshaping procedures that involve irradiation through intact skin or mucosa, cooling adjuncts are employed to protect the overlying superficial tissues from thermal damage.

Charring
See Carbonisation.

Chromophore
A coloured substance in the body which absorbs laser light. *e.g.*, melanin is a chromophore in the skin.

Cladding
Outer protective layer covering the core of the fibre. It has a smaller refractive index as compared to the core, so that maximum internal transmission can occur, without much loss.

CO_2 laser
See Laser wavelength.

Coagulation
Separation or precipitation of suspended particles in a fluid. A coagulum is formed when proteins in the tissue are heated and denatured by thermal energy. Coagulation results in an irreversible cellular damage. It is absorbed by an inflammatory process with formation of scars. In laser surgery, formation of coagulum is useful for haemostasis. It also seals the wound and forms a barrier against infection of the wound.

Coherent light
Radiant electromagnetic energy of the same, or almost the same wavelength, and with definite phase relationships between different points in the field.

Continuous wave (CW)
Continuous operation of a laser, such as the CO_2 laser (unlike the pulsed operation of a laser such as the Ho:YAG laser, which has a period of non-exposure, interspersed in between pulses).

Confocal reflectance microscopy
Confocal reflectance microscopy differs from a conventional microscopy in that it uses a point source of light, typically a laser, to illuminate a small spot within tissue. Backscattered (or reflected) light from the tissue is captured through an aperture, which matches the size of the illuminated spot placed in front of the detector. The aperture spatially filters light returning from out-of-focus planes within the tissue, imaging only the plane in focus. The gray-scale image created is an optical section representing one focal plane within the examined specimen.

Conduction of laser energy
The energy is conducted in to the depth of tissue, resulting in thermal damage beyond the visible laser crater. The thermal damage zone consists of a first few hundred microns zone of immediate cell death (thermal necrosis). The next few hundred microns of tissue suffer denaturation of the proteins (thermal coagulation). Both thermal necrosis and thermal coagulation are irreversible and cause permanent cell death.

Colour
The colour of laser light is defined by the wavelength.

Collimated beam
Beam in which all, or almost all, of the photons are travelling in the same ‘parallel direction’. In nature, it is not possible to produce a beam which is perfectly parallel because there is always a tendency for diffraction at the edge of the path.

Cumulative dosage
Unlike radiotherapy, the usage of a laser beam has no cumulative effect on the tissue. Therefore, there is no upper limit to the laser exposure for ablation, neither is there any limit to the number of laser procedures which could be undertaken on a particular tissue.

Defocused beam
The incident beam is said to be defocused when it is not at the focal point on the target. The defocusing is carried out by moving the laser hand-piece and increasing the distance between the laser source and the target. A defocused beam merely heats up the tissue rather than vaporising it. The ‘cooking effect’ is like the diathermy effect and helps haemostasis. The thermal effect spreads over a larger area with much less penetration within the tissue.

Dichroic
A surface, which reflects different colours when seen from different directions.

Differential path-length spectroscopy
Differential path-length spectroscopy is considered to be a form of elastic scattering spectroscopy (q.v.) but with fixed photon pathlength, fixed photon visitation depth and absolute measurement of absorbers. Optical pathlength of photons is constant within reasonable range of optical properties. The signal

combines information about intracellular morphology, cell biochemistry (bilirubin/betacarothene) and microvascular properties (oxygen saturation and average vessel diameter).

Diode laser
A laser diode is an *electrically* pumped semiconductor laser in which the active medium is formed by a semiconductor diode similar to that found in a light-emitting diode. The 800nm – 980nm units have a high absorption rate for haemoglobin and thus make them ideal for soft tissue applications, where good hemostasis is necessary.

Divergence
A spreading of the beam as it moves away from the laser aperture or the laser fibre.

Duty cycle (%)
A ratio between the ON time and the total cycle time (T), given as a percentage: duty cycle (%) = ON time / T x 100.

Dye lasers
Lasers which have liquid dye as laser medium.

Elastic scattering spectroscopy
Exposure of tissue to light results in a series of absorption and scattering events. The light beam undergoes single or multiple elastic scattering which implies that the light returns with the same energy as the incident photons. The extent of the scattering effect depends on the relationship between the wavelength of the light and the particulate size. A scattering event carries with it all the characteristics of the cellular components, which are called ‘scattering centres’. These centres can be normal or pathological. Normal centres are nucleus, nucleolus, chromatin content and metabolic organelles. Pathological centres may be in the form of disorganised epithelial orientation and architecture, changes in morphology of epithelial surface texture and thickness, cell crowding, increased distance from subepithelial collagen layer, enlargement and hyperchromicity of cell nucleus, increased concentration of metabolic organelles and presence of abnormal protein packages or particles. These cellular and subcellular changes are identified by using the refractive indices of the cellular components. The resultant scattered light (elastic light scattering process) is then collected and analysed by a spectrometer and a spectrum is generated.

Electromagnetic (EM) radiation
Flow of energy related to the vibration of the electric and magnetic waves.

Electromagnetic (EM) spectrum
The whole range of electromagnetic waves separated by wavelength.

Exposure time
Time (seconds) in which the laser beam, working in continuous or pulsed mode, strikes the target.

Eye safety
Lasers at certain wavelengths (700nm to 1400nm) represent a particular risk to the retina of the eye, because the lens of the eye focuses the collimated light onto a very small point on the retina which greatly increases the intensity. Accidental exposure to laser light, even at very low powers (in the order of 1 milliwatt) can result in permanent damage to the eye.

The cornea is opaque to the CO_2 laser wavelength. If it is struck with a CO_2 laser beam, corneal damage can result.

Fibre core
The inner part of the optical fibre which transmits the laser beam with internal reflections. The core is covered with cladding for protection from damage, etc.

Fibre transmission
Some lasers, such as Nd:YAG, KTP, Er:YAG and the Ho:YAG, are fibre transmissible. However, the CO_2 laser is not fibre transmissible via commonly available optical fibres made from silica. It can be transmitted via hollow waveguide. Although sometimes used synonymously with the optical fibre for their property of transmission, a waveguide is not an optical fibre.

Fire
Combustion of flammable material results in fire. For combustion to occur there are three prerequisites: an ignitor, combustible material and the presence of a combustion-supporting gas such as oxygen. Once combustion occurs, the fire can be self-sustained, and does not require continuous presence of an ignitor. Following ignition of a combustible material, the temperature rises; smoke emanates and is replaced by a flame. Depending on the material, the fire spreads. If all these stages occur in a

very short time, there is conflagration. If the PVC anaesthetic tube ignites, it will burn furiously, and the result is not just a fire but conflagration. The source of ignition is the laser beam. In laryngeal surgery, the obvious flammable material is a rubber or a polythene endotracheal tube. Oxygen is present even in a higher concentration than in the air in the laryngeal area. It is therefore clear that a potential fire hazard exists in the laser surgery of the larynx. Further fire hazard comes from dry swabs, naso-gastric polythene tubes, tooth guards, plastic tracheostomy tubes, etc. Safety precautions should be made, such as avoiding the flammable material in the beam path, or providing protection if avoiding is impossible.

Fireproof endotracheal tube
Only flexible all-metal endotracheal tubes are truly fireproof. They neither ignite nor combust. Some silicone-coated tubes will ignite, but will not combust. These are marketed as laser-safe tubes. Nevertheless, fire precaution is still necessary since their ignition may result in a tracheal burn. Conventional rubber and plastic tubes will ignite and combust, they need to be protected with wet gauze.

Fluence
On laser equipment, this is often used to define radiant exposure, or energy per unit area. It is expressed as Jm^{-2} or, often on laser equipment consoles, as J/cm^2.

Fluorescence imaging
All tissues fluoresce due to the presence of fluorescent chromophores (fluorophores) within them. The fluorescence can either occur as autofluoresence (if induced by UV light), or as a laser-induced phenomenon enhanced by either topical or systemic application of 5-aminolaevulinic acid (ALA). Fluorescence spectroscopy can detect these substances and provide characteristic spectra that reflect biochemical changes occurring within the tissue. Commercially available fluorescence imaging equipment aims at highlighting malignant tissue, especially where it is not evident under white light in a large field of view.

Focused beam
When the laser spot is sharply focused on the target, the energy is maximally concentrated. Thus the tissue destruction is maximal when the beam is sharply focused.

Foot switch/hand switch
Devices used to operate the laser.

Frequency (f)
Number of pulses per second, usually expressed in Hertz (Hz).

Fresnel reflection (or loss)
When a beam travels from one medium to another, some of it is reflected at the interface. The reflected energy is called 'Fresnel loss'.

Gas state lasers
Gas state lasers have a gas or, more usually, a mixture of gases within a tube as lasing material. The most common gas laser is Helium-Neon, with a primary output of 632.8nm, which is in visible red. Other gas lasers are CO_2, argon, KTP and krypton.

Gaussian beam
The laser beam is produced in a number of modes. The electromagnetic (EM) waves in transverse EM mode (TEM) travel in a direction which is close to the axis of the beam. A beam which has 90% of the energy concentrated in the central area of the bell shaped beam is known as a Gaussian beam.

Hertz (Hz)
A unit of measure of frequency, or cycles per second.

Infrared-A (*see* also Near infra red)
Defined as light in the wavelength range 700nm to 1400nm.

Infrared-B/C (far infra red)
Defined as light in the wavelength range 1400nm to 1mm.

Institute for Safety in Office Based Surgery (ISOBS)
The Institute for Safety in Office-Based Surgery, Inc. (ISOBS) is a national non-profit organization founded in 2009 in Boston, Massachusetts (USA) by physicians to improve the safety of office-based surgery through physician education, research, and patient advocacy.

Invisible laser
Laser with wavelengths that do not produce a sensation of vision.

Irradiance (Wm^{-2})
Laser power per unit area.

HPD (haematoporphyrin derivative)
A dye injected to sensitise malignant tumour tissue so that photodynamic destruction can be selectively undertaken.

Joule (J)
Unit of energy.

Joystick
The joystick is used like a paint brush, to move the spot over a short distance on the target seen through the microscope.

Laser light
Laser light usually describes an intense beam of optical radiation. It is different from all other light sources in the way it is generated. Typically, laser light exhibits the following properties: (1) Single colour (monochromatic); (2) Collimated (non-divergent).

Lasers are typically named according to their 'laser medium'. This is the material that sits inside a 'cavity' in a laser machine where the laser light is generated. Each laser medium emits light of characteristic wavelength(s).

Laser beam
A narrow beam of coherent, powerful, and nearly monochromatic electromagnetic radiation emitted by a laser source.

Laser crater
A single strike of laser energy on soft, water-containing tissue results in immediate vaporisation. The loss of tissue results in an ulcer crater. Since the distribution of the energy across the whole area of the laser spot is not even, the crater is U-shaped. The crater bed consists of a layer of thermal damage zone, beyond which the tissue is normal. The thermal damage zone consists of two layers; the superficial layer shows a zone of thermal necrosis, whereas the deeper layer shows a zone of thermal coagulation. Both these layers suffer irreparable damage.

Laser effects
The interaction of laser radiation with tissue may produce thermal and non-thermal processes. Non-thermal processes may be photomechanical, as in ophthalmic surgery, or photochemical, in which the photochemical activation of sensitised cell produces a transient release of singlet oxygen toxic to the cells. When laser radiation strikes a tissue, the temperature begins to rise. Coagulation begins when temperature is between 60°C and 100°C. Vaporisation takes place when the temperature is raised to 100°C. The char starts to burn at around 400°C-500°C.

Laser efficiency
The measure of levels of energy input against power output. The greater the inefficiency, the more power is needed for the same output.

Laser fibre
See Optical fibre.

Laser light
See Laser.

Laser plume
A laser strike on tissue produces a laser plume which consists of vapour, smoke produced from ignition of the solid contents of tissue and necrotic-cell material released as a result of micro-explosions due to disruption of cell structure resulting from expansion of steam within the cell.

Laser safety management
A protocol whereby the risks from the lasers (including non-beam hazards) are assessed and appropriate safety controls put into place. Controls may include: (1) Equipment and facility design; (2) Administrative controls, such as training and written procedures; (3) Personal protection equipment.

Laser workers
In laser safety, defined as those who may be exposed to laser hazards. In theatres, these are often grouped in two categories: (1) Authorised users, those who are authorised (by their employer) to operate the laser equipment, *e.g.*, the surgeon; (2) Assisting staff, *i.e.*, any other staff present in the laser facility whilst treatment is in progress.

Lasing media
Lasers are commonly designated by the type of lasing material employed to produce stimulated emission. There are four types: solid state, gas, dye and semiconductor.

The speed of light in a vacuum

The speed of light in a vacuum, c is 3 x 10^8 ms^{-1}.

Light-induced fluorescence endoscopy (LIFE)

Light-induced fluorescence endoscopy is a real-time diagnostic bronchoscopic imaging system that delivers a blue light (442nm) from a helium-cadmium laser beam .The blue laser light acts as an excitation source that induces differential autofluorescence of the cancerous and dysplastic tissues. Two image-intensifying charged couple device cameras capture this weak, low-intensity fluorescence. The computer then processes these signals into a real-time colour pseudo-image. Normal mucosa is arbitrarily assigned a green colour. A red or brownish-red colour suggests dysplastic or cancerous tissues.

Maximum permissible exposure (MPE)

In laser safety, the MPE is defined as the level of optical radiation to which, under normal circumstances, persons may be exposed without suffering effects. MPEs are expressed in terms of irradiance (Wm^{-2}) or radiant exposure (Jm^{-2}).

Metric measurements

Text	Symbol	Factor
tera	T	1000000000000
giga	G	1000000000
mega	M	1000000
kilo	k	1000
hecto	h	100
(none)	(none)	1
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	µ	0.000001
nano	n	0.000000001

Micro-endoscopy

Micro-endoscopy involves examining tissue *in situ* at a magnification from 60x to 1000x. At this magnification, details of tissues, cells and cellular ultrastructures can also be observed to detect specific patterns for pathology, *e.g.*, inflammation, metaplasia, dysplasia, and malignancy.

Micromanipulator

See Joy stick.

Mitomycin-C

Mitomycin-C is a potent antibiotic derived from the *Streptomyces caespitosus* bacteria which can modify wound healing at the molecular level and has been used to interfere with post-surgical scar formation. It was first reported in the ENT literature for the treatment of tracheal scarring after tracheal reconstruction in a small case series. A number of randomised prospective animal studies have shown impressive results in prevention of post-operative glottic and subglottic stenosis following surgery to the airway. Its use in airway surgery has become fairly routine, yet, there are no randomised controlled trials proving its efficacy.

Modes of operation

See Pulsed and continuous wave.

Monochromatic

Monochromatic light refers to light of a single colour. In practice, monochromatic laser usually emits in narrow waveband.

Near infrared

This is typically defined as light emitting at 700nm to 1400nm. Whilst lasers in this region are invisible to human eye, the invisible beam can pass through the anterior structures of the eye and damaged retina.

Near-infrared spectroscopy

Absorption and transmission of near-infrared light in biological tissue provides information about haemoglobin concentration (*i.e.*, oxy- and deoxy-hemoglobin).

Nominal ocular hazard distance (NOHD)

Defined as the minimum distance from the light source (laser) at which the exposure to the beam falls below the maximum permissible exposure.

Non-beam hazards

In laser safety, the chief hazard is damage to the eye/skin. However, electrical, mechanical, plume, fire and other environmental hazards should also be taken into consideration.

ON time and OFF time

The time duration that the laser is operative within the cycle time (T) is called the ON time, whereas the time duration that the laser is inoperative within the time cycle (T) is called the OFF time. Thus cycle time (T) = ON time + OFF time.

Office-based laryngeal procedure

Office-based laryngeal procedures cover diagnostic, therapeutic and monitoring procedures.

Office based surgery
Office-based surgery means any surgical or other invasive procedure performed on the patient in a location other than a hospital or a diagnostic treatment centre, including free-standing ambulatory surgery centres.

Optical coherence tomography (OCT)
Optical coherence tomography (OCT) uses light to determine the cross-sectional anatomy in turbid media such as living tissues. OCT is analogous to ultrasound imaging except that it uses light rather than sound. The high spatial resolution of OCT enables non-invasive *in vivo* 'optical biopsy' and provides immediate and localised diagnostic information. OCT images are formed by dividing light from an optical source into two paths, one of which is directed to the tissue sample, and the other to a reference mirror. Light reflected from the sample is recombined with light from the reference mirror and detected, forming an interference signal only when the lengths of the sample and reference paths are matched to within a short distance termed the coherence length of the light source.

Optical density (OD)
In the context of laser safety eyewear, the optical density is a measure of how much protection the eyewear should provide.

Optical diagnostic biopsy
Optical diagnostic 'biopsy' (optical biopsy) involves the use of light of varying wavelength to examine the suspect tissue. The optical diagnostic methods are not aimed at differentiating between normal and abnormal tissue, since this can easily be achieved by direct or endoscopic visualisation. Optical diagnosis aims to provide differentiation of areas of similar clinical characteristics, *e.g.*, dysplasia versus carcinoma *in situ*.

Optical radiation
Light (from a laser or other source) is often described as optical radiation.

Optical fibres
A long rigid or flexible thin thread of fused silica, or other plastic transparent substance, used for transmission of laser energy to target tissue, by internal reflection.

Optical spectrum
Refers to the section of the electromagnetic spectrum of 10nm to 1mm. This includes ultraviolet, visible light and infrared. *See also* Wavelength.

Paediatric tracheostomy tube size
The following formula gives a quick guide to the size of the tracheostomy in children: Size of tube = age/4 + 4. Thus, a four-year-old child would require a size five tube.

Period or cycle time (T)
The time interval between the onset of two consecutive pulses (T = 1/f; T is inversely proportional to pulse repetition frequency,f.)

Peak power (P_{peak})
The maximum power delivered by the laser beam during emission.

Personal protective equipment (PPE)
In the context of medical laser work, this mainly refers to eyewear but can include masks and gloves.

Photochemical effect
See Laser effects.

Photochemical internalisation
Multiple-drug resistance is an expected risk in clinical oncology. Acidification of endocytic vesicles and increase in cytosol pH is one of the most common causes for resistance. This usually leads to trapped chemo-active agents in endocytic vesicles and eventually phenotypic drug resistance. Photochemical internalisation involves photochemically damaging the endocytic vesicles and thus releasing macromolecules into the cytosol.

Photodynamic therapy (PDT)
PDT is a two-step process requiring the administration of a light-absorbing chemical (photosensitiser) and the delivery of light from a non-thermal laser. PDT is based on initial sensitisation of the target tissue with an agent with photosensitising properties. The agent selectively accumulates in target tissue. The subsequent light delivery to the target tissue results in cellular destruction by a non-free radical oxidative process. The photochemical reaction following PDT is non-thermal.

Photomechanical effect
See Laser effects.

Photon
A massless particle, the quantum of electromagnetic field, carrying energy, emitted by an excited atom.

Photosensitiser
An agent which accelerates the absorption of a particular waveband by a tissue.

Plasma
In physics, an ionised gas, at high temperature

Plume
During routine laser surgery, a large amount of surgical smoke is produced at the site of the operation, and spreads into the operating room. Standards have eliminated the term smoke, and refer to all airborne contaminants resulting from vaporising tissue with energy-based devices (lasers, diathermy, ultrasonic instruments, etc.) as 'surgical plume'. Plume is a combination of smoke, cellular particulates, organic materials, inorganic materials, and gases.

Plume extractor
Air suction device used in theatres to reduce the laser plume.

Power (P)
Energy per second expressed as joules per second, and measured in watts (W) Power P = 1 watt (W) = 1 joule (J)/s.

Power density (p)
Also defined as irradiance (R). Power density is power P incident on a unit area (A) and measured in W/cm^2. Power density $p = P/A$.

Polychromatic
Light source consisting of multiple wavelengths.

Popcorn effect
Explosion of deeper tissues when power settings greater than 50 watts and a pulse duration of more than one second is used, causing damage to the surrounding tissue.

Poiseulle's law
Poiseulle's law states that, within a tubular structure, there exists an inverse relationship between resistance to flow and the radius of that structure to the fourth power. Application of this law explains a 16-fold increase in airway resistance following swelling of submucosa of an infant's subglottic just by a mere one mm. A similar increase in an adult would only produce a three-fold increase in resistance. This explains the rapid manner in which paediatric airway patients can suddenly decompensate with an almost totally obstructed airway.

Pulse width (τ)
The pulse duration at half peak power level.

Radiant energy
A product of power (watts) and time (s), measured in joules.

Raman spectroscopy
Raman spectroscopy is used in physics and chemistry to study vibrational and other low-frequency modes in a system, enabling chemical characterisation and structure of molecules in a sample. It relies on inelastic scattering (loss or gain of energy) of monochromatic light, usually from a laser in the visible, near infrared or near ultraviolet range. The laser light interacts with molecular vibrations, resulting in the energy of the laser photons being shifted up or down. The shift in energy gives information about the phonon modes in the system. Raman spectroscopy is complementary or even an alternative technique for biopsy, pathology and clinical assays in many medical technologies.

Repeat pulse
In repeat mode, the laser beam is delivered intermittently as a series of bursts, for as long as the footswitch is pressed. The duration of each burst (pulse) is determined by the ON time selection (emission duration). The time interval between bursts (pulses) is determined by the OFF time selection.

Repetition rate
Rate of repetition of pulses per second, expressed as Hertz (Hz).

Reflection of laser energy
When the beam strikes the tissue, very little energy is reflected from its surface – a large majority is either absorbed, or conducted. However, on a reflective surface such as the instruments, the incident laser beam will reflect. The reflected laser beam will be defocused and thus rapidly lose its energy. Nevertheless, within a short distance of reflection, the energy content will be sufficient to result in ghost burns of non-target tissue, or ignite combustible material such as the plastic anaesthetic tube.

Risk management
In any well-designed specific plan of treatment, benefit outweighs the possible harm or risk inherent to the proposed treatment. Risk management is a continuum of the treatment plan and involves a dynamic approach to the principle of a risk and hazards which are identified, and positive steps taken to protect the patient from harm.

Scatter of laser energy
Although principally the thermal damage zone occurs due to conduction of the laser energy into the deeper tissue, it also occurs due to a phenomenon known as 'scatter'. The laser energy is reflected within the tissue in a haphazard way, thus producing a much deeper thermal damage zone than that produced merely by conduction. Some lasers (for example Nd:YAG Laser used as free beam) scatter considerably more within the tissue than other lasers (CO_2).

Semiconductor laser
See Diode laser.

Selective photothermolysis
The concept of selective photothermolysis is based on the peak absorption coefficient of haemoglobin for wavelengths emitting at ~571nm and ~541nm. The pulsed-dye laser (PDL) emitting at 585nm and the pulsed-KTP laser emitting at 532nm are specifically and selectively absorbed by haemoglobin. The energy is delivered over a short pulse width. It passes through the perivascular tissue and the vessel wall without significant absorption. It is maximally absorbed by the blood within the lumen, heating and coagulating it. Selective heating of blood in the microcirculation without rupturing the vessel or causing collateral damage to perivascular tissue provides a platform for vocal fold laser surgery by angiolysis.

Single pulse
In the single-pulse mode, the laser beam is emitted as a single pulse or as a single burst (for super pulse and sharpulse) for a preset duration (ON time), or until the footswitch is released, whichever comes first.

Sleep-related breathing disorder
Sleep-related breathing disorder is essentially a spectrum of clinical entities ranging from primary or simple snoring to severe obstructive sleep apnoea (American Sleep Disorders Association, 1997).

Solid state laser
These use active lasing material distributed in a solid matrix.

Spot size
The spot size is measured in microns (μ). The older generation CO_2 micromanipulator (Microslad) provided a spot with a diameter of 700μ. In a Gaussian beam mode, the energy distribution across the whole of the area of the spot is not even. The energy is maximally concentrated towards the centre of the spot, losing its power toward the periphery of the spot (Gaussian, or TEM00 mode). At any given energy, for all practical purposes, the power is evenly distributed over the entire area of the spot.

Stent
A dental impression material originally used as a template to support skin grafts for repair of oral trauma, invented by Charles Thomas *Stent,* a British dentist in the late nineteenth century. In modern times, the term is used to describe devices for maintaining the patency of tubular structures, including the tracheo-bronchial tree.

Target tissue
Target tissue is the tissue targeted for laser treatment. Non-target is everything other than the target tissue. In the laryngeal surgery this would include teeth, lips, flammable material such as swabs, tubes, etc.

Thermal damage zone
See Laser crater.

Thermal effects
See Laser effects.

Tissue ablation
The rate of tissue ablation depends on the power density. The power density is directly proportional to the power setting. The greater the power density, the more rapid is the tissue ablation.

Tissue interaction
The tissue effect of any laser depends on primary tissue interaction. The tissue interaction depends on the property of a particular wavelength and the type of tissue. The interaction is also influenced by laser parameters such as power setting, exposure time, etc.

Therapeutic beam
Any laser beam used to perform treatments.

Topical anaesthesia
The term topical anaesthesia covers administration of an agent to produce a transient and reversible loss of sensation in a defined area of the body. It is carried out without supplemental medication, on conscious unsedated patient.

Tunable laser
A laser which is designed to emit at a number of wavelengths, over a limited spectral range.

Units of measurement
Radiant energy, Joules, J; Radiant power, watts, W (joules per second); Radiant exposure (Jm^{-2}) – Energy per unit area. This is sometimes defined as 'fluence' on laser equipment, unit: J/cm2 ; Irradiance (Wm^{-2}) – Power per unit area.

Ultraviolet (UV) Light
Defined as the region of the optical spectrum between 10nm and 400nm. UV light is invisible to the human eye.

Vaporisation
When the laser beam strikes the tissue with sufficient energy, the intra-cellular water boils and steam is produced. The steam expands within the cell, resulting in a micro-explosion of the cell and its destruction. The steam escapes, resulting in vapour production. This way, the laser can be used to vaporise a given tissue.

Vaporisation / excision
The laser can be used to ablate a given tissue by vaporising it, layer by layer. On the other hand, the laser can also be used to 'excise' a tissue, by vaporising the narrow band of tissue in the line of excision. Continuing exposure of the tissue in the line of excision will deepen the cut. Retraction of tissue will accelerate the process and deepen the cut, eventually separating the tissue completely.

Visible laser
Lasers with a wavelength capable of causing sensation of vision.

Visible light
Defined as the region of the optical spectrum between 400nm violet to 700nm red.

Waveguide
A Waveguide consists of a hollow plastic tube coated with a dielectric silver iodide film, which in turn is covered with a metallic silver film. The beam is reflected off the inner wall of the tube until it exits at the tip. The waveguide is used for CO_2 laser transmission, since this wavelength cannot be transmitted down a commonly available optical fibre. The CO_2 laser energy passes through a hollow CO_2 'fibre' confined by a series of concentric mirrors whose thickness and the gap between them corresponds to the wavelength of the CO_2 laser, *i.e.*, 10,600nm. The fibres are cooled by the passage of gas (air or helium) through the core. Waveguides are bulkier, less flexible and cause significant loss of power during transmission.

Watt
Unit of power. One watt is equal to 1 joule per second.

Wavelength
In optics, the wavelength defines the 'colour' and is summarised in the table below.

Colour	*Wavelength Range*
Ultraviolet (invisible)	100nm to 400nm
Visible light	400nm violet to 700nm red
Infrared-A (near infrared)	700nm to 1400nm
Infrared-B/C (far infrared)	1400nm to 1mm

1nm = 1,000,000,000th of a metre.

Appendix IV

Low-level laser therapy in the management of chronic cochlear tinnitus

V. Oswal

1. Introduction

Level laser therapy (LLLT) for chronic *cochlear* tinnitus has been included under 'Appendix,' since there is no consensus as to its effectiveness in the management of tinnitus of unknown aetiology. As to any risk associated with this unproven therapy, there is one report from Nakashima in 2002 of a patient experiencing acute hearing loss after the third laser treatment. Prospective reader is advised to look up the literature in detail before embarking on this, yet inconclusive, application of the laser technology.

2. Basic science

Surgical lasers have high energy levels and thus are capable of tissue ablation. Such lasers are sometimes called 'hard lasers'. Lasers with much lower energy output are known as 'soft lasers' or 'low-level lasers (LLT). Typically, the soft laser emits in the range of 600-1000 nm (red to near infrared). The average power is in the range of 1-1500 mW. Some high-power soft lasers have a short pulse width of 200s and a high peak power in the range of 1-500 mW.

2.1. The mechanism of therapeutic effect

The therapeutic effects are at cellular level. Application of LLLT may result in an increase in reactive oxygen species and proliferation of cells. Another mechanism may be related to stimulation of mitochondria. A detailed description of the mechanism of action is beyond the scope of this work.

2.2. Clinical application

There have been several studies demonstrating biological and physiological effects of LLLT in enhanced recovery of peripheral nerve injury. Tauber *et al*. (2003) proposed that LLLT could be beneficial in cases of cochlear dysfunction causing tinnitus. The main emphasis of their work was accurate dosimetry to the cochlea by controlled positioning of the laser light fibre within the external auditory meatus. To this end, they designed a new specific head set applicator.

Although LLLT has been used in a variety of conditions such as acute pain, rheumatoid arthritis, osteoarthritis, chronic joint disorders and so on, a Cochrane Library review (http://www.chat-hyperacusis.net/post/Low-Level-Laser-Therapy-for-Tinnitus-A-REALITY-CHECK-5017816) concluded that there is insufficient evidence for the use of low level laser therapy for the treatment of non-specific disease entities.

2.3. Factors influencing the effects of LLLT

The effects of LLLT are determined by several variables: specific wavelength of laser, duration of treatment, power setting, the target tissue, dose-rate effect, beam penetration, the beam coherence, and repetition rate. With so many variables, comparison of the outcome of intra-patient, inter-patient and inter-institution therapy is well-nigh impossible and has constrained its wide-spread use.

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2.4. Delivery of laser light

Tauber *et al*. (2001) studied the effectiveness of trans-meatal against trans-mastoid positioning of the laser light using human temporal bones and concluded that the trans-meatal positioning was superior to cover most of the target (cochlea) with irradiation.

3. Literature review: LLLT for chronic cochlear tinnitus

Tauber *et al*. (2003) used two wavelengths, 635 nm and 830 nm. The power setting was 7.8 mW and 20 mW, respectively. After a follow-up period of six months tinnitus loudness was attenuated in 13 of 35 irradiated patients, while two of 35 patients reported their tinnitus as totally cured. There was no change in the hearing threshold levels.

Cuda and De Caria (2008) studied the effectiveness of combined counselling and low-level laser stimulation in a randomly controlled group suffering from disturbing chronic tinnitus. A wavelength of 650 nm was used at a power setting of 5 mV for twenty minutes daily for three months. The Tinnitus Handicap Inventory showed a decrease in the severity of tinnitus in 61% in the irradiated group as compared to 35% in the placebo group.

Gungor et al (2008) used a five-point scale to assess the various parameters of tinnitus including loudness, duration and degree of annoyance. A reduction of one point on the scale was accepted as improvement. Using 650 nm wavelength at 5 mW power trans-meatally for 15 minutes daily for one week, they noted that the three parameters showed improvement in half the patients treated with the laser, but in none of the patients treated with a placebo laser.

In a retrospective study using a multi-modal treatment which included the soft laser, Hahn *et al*. (2008) found that there was no *objective* improvement in the symptoms, although improvement was reported by a Visual Analogue Scale (VAS).

Aigner *et al*. (2006) studied the effects of adjuvant treatment with laser acupuncture on tinnitus in the chronic phase following whiplash injury. They concluded that the adjuvant laser acupuncture with a 5 mW HeNe laser and an irradiation time of 15 s appeared to be *ineffective* in the management of tinnitus following whiplash injuries.

Okhovat *et al*. (2011) found that although low-level laser therapy offered significant benefit in tinnitus, the results were influenced by gender, job, and age categories. They caution that part of observed treatment effect may be due to the phenomenon of 'Regression Toward The Mean' and also to some degree of 'Hawthorne effect' (q.v.) in uncontrolled trials. They advocate the use of randomised control trials to mitigate these biases.

Teggi *et al.* (2009) used LLLT (650nm, 5mW, 20 min/day for three months) to perform a prospective, randomised double blind study on 60 patients and concluded that LLLT offered *no* demonstrable therapeutic benefit for tinnitus management.

The true rate of failure may not be apparent, since negative results are usually not reported in the literature.

4. LLLT for tinnitus

Most workers have used a soft laser emitting at 650 nm with a power setting of 5 mW as a source of low-level laser energy. The laser irradiation is applied by placing an optical fibre in an adapter with a soft silicone tip in the ear canal. The beam is directed on to the tympanic membrane. It passes through the tympanic membrane and strikes the cochlea.

5. Benefit and risk issue

Okhovat *et al.* (2011) did not notice any adverse effects on the patients following the LLLT treatment for tinnitus. Likewise, none of the patients suffered from increased tinnitus severity as result of treatment.

However, as noted above, Nakashima (2002) reported one patient experiencing acute hearing loss after the third laser intervention.

The benefit and its extent on tinnitus alleviation are not conclusive on account of multivariate factors:

i. Tinnitus is a subjective symptom and its pre- and post-therapy status is measured by Visual Analogue Scale (VAS), leaving room for errors due to individual interpretation. Furthermore, the subjective outcome measure may be influenced by the '*Hawthorne effect'* whereby subjects improve or modify an aspect of their behaviour being experimentally measured, simply in response to the fact that they know they are being studied.

ii. Study design is not uniform. Variations are unavoidable since the duration of each treatment, number of treatments carried out and the laser parameters are not uniform.

iii. The age and the sex of the sufferer may also influence the outcome. Okhovat *et al*. (2011) found that the benefit was most if the patients were young.

Noise level at work may also influence the outcome.

6. Conclusion

At the time of writing, the use of LLLT in the management seems empirical and the reports in the literature are equivocal (Langguth 2007).

Partheniadis-Stumpf (1993), Mirz (1999), Nakashima (2002) and Teggi (2009) concluded that LLLT failed to alleviate tinnitus. On the other hand, Shiomi's preliminary report (1997), Tauber's feasibility study, and Gungor's report concluded that LLLT can be an effective addition in the management of tinnitus.

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The Hyperacusis Network Message Board: http://www.chathyperacusis.net/post/Low-Level-Laser-Therapy-for-Tinnitus-A-REALITY-CHECK-5017816

Answers MCQ

Chapter 32:
1c, 2ab, 3b, 4bc, 5cde, 6d, 7acd

Chapter 33:
1e, 2cd, 3e, 4d, 5acde, 6ade, 7acd

Chapter 34:
1ade, 2bc, 3bde, 4ad, 5e, 6f, 7e, 8cd, 9cd

Chapter 35:
1ade, 2ade, 3e, 4acd, 5c, 6bd, 7b, 8c, 9ae, 10c, 11d, 12b, 13d, 14c

Chapter 36:
1be, 2cde, 3ac, 4bcd, 5b, 6ade, 7c, 8ce, 9acd, 10c, 11e

Chapter 37:
1cd, 2b, 3b, 4bde, 5cd, 6ade, 7ce, 8ad, 9bc, 10c

Chapter 38:
1c, 2be, 3e, 4ab, 5bcd

Chapter 39:
1b, 2bce, 3d, 4bcd, 5e, 6ad

Chapter 40:
1bc, 2ab, 3c, 4e, 5b, 6bcd

Chapter 41:
1bcd, 2a, 3bd, 4bcd, 5abc, 6ace, 7bde, 8e, 9f

Chapter 42:
1acde, 2abe, 3bcde, 4ace, 5ce, 6bde, 7ad, 8abd

Chapter 43:
1c, 2bd, 3bc, 4cde

Chapter 44:
1e, 2ac, 3a, 4abde, 5abde, 6abc

Chapter 45:
1cd, 2bcd, 3bc, 4b, 5e, 6e, 7c, 8acde, 9ad, 10d, 11f

Chapter 46:
1de, 2ab, 3e, 4bcd, 5be

Chapter 47:
1e, 2ad, 3acd

Chapter 48:
1c, 2bcd, 3abc, 4abcd, 5d

Chapter 49:
1bd, 2e, 3abde, 4bcde, 5bd, 6ae, 7abc, 8bc, 9d, 10ce

Chapter 50A:
1abc, 2ac, 3a, 4e, 5bc

Chapter 50B:
1bce, 2e, 3cd, 4bcd

Chapter 51:
1a, 2e, 3ade, 4acd, 5cd, 6de, 7ac

Chapter 52:
1b, 2ab, 3e, 4ade, 5abc

Chapter 53:
1ab, 2ad, 3b

Chapter 54:
1c, 2abe, 3e, 4d

Chapter 55:
1ab, 2bce, 3bce, 4cd, 5e, 6e, 7bcd, 8c, 9e, 10d, 11e, 12bcde, 13e

Chapter 56:
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Chapter 57:
1acd, 2e, 3abd, 4acde, 5ade, 6e, 7d, 8bc

Chapter 58:
1bd, 2abce, 3f, 4a, 5acde, 6ae, 7e

Chapter 59:
1bd, 2bcde, 3b, 4c, 5abde

Chapter 60:
1abde, 2be, 3abe, 4bcde, 5acde, 6e, 7e, 8e, 9be, 10e, 11bcd, 12de, 13acde, 14abe

Chapter 61:
1be, 2bce, 3bce, 4cde

Chapter 62:
1c, 2e, 3bcd, 4be, 5bcd

Chapter 63:
1cde, 2ab, 3f, 4ce, 5b, 6cd, 7abde, 8abde

Chapter 65:
1e, 2cde, 3abde, 4d

Chapter 66:
1acd, 2bde, 3ac, 4ade, 5acd, 6bde, 7ade, 8bc, 9e, 10 acd, 11bcd, 12bcde

Chapter 67:
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Principles and Practice of Lasers in Otorhinolaryngology and Head and Neck Surgery

This second and enlarged edition is built upon the success of the first edition published in 2002. From the conceptual beginning of commissioning the second edition, this work has taken three years to come to fruition. It is covered in some 67 chapters, signifying the present, emerging and future trends in medical applications of lasers. The chapters have been contributed by some 59 internationally recognised authorities who were recruited for their expertise in a particular laser topic. The pro forma has undergone some metamorphosis. While the sectional demarcation retains the well-trodden path of anatomical delineation, the chapters have been rearranged along the familiar disease or dysfunctional notations used in everyday practice. Each chapter is sumptuously presented with high-quality colour photographs. The Multiple Choice Questions (MCQ) at the end of each chapter provide a simple recall test and prompts revision where necessary. A continuing support is provided by the ubiquitous website dedicated to the book title.

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Mr Oswal's interest in the laser technology, dating back to the seventies of the last century, culminated in the acquisitions of the Coherent® CO2 laser in 1981 with funds raised by public appeal. The fledgling technology required much pioneering work with bench experiments to evaluate laser biophysics for its clinical applications. He established a number of laser training courses in the UK and internationally and has been awarded with honorary membership of Otolaryngology Associations of many countries. He has written and presented widely on various laser topics. He has chaired laser sessions at the international conferences organised in countries all over the globe. He is an Associate Editor of Lasers in Medical Science, past Editor-in-Chief of ENTNews and member of the editorial board of a number of laser journals.

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